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THESIS

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AUTOMATED FIBER OPTIC MEASUREMENTS

by

Francisco Carlos Melo Pantoja

December 1989

Thesis Advisor: John P. Powers

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Automated Fiber Optic Measurements

by

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Captain, Brazilian Air Force
B.S., Federal University of Pará, 1977

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

from the

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December 1989

of electrical and Computer Engineering

ABSTRACT

The objective of this work was to implement an automated optical measurement system for use with fiber optic systems. This system controls data acquisition, processes the acquired data and optimally displays results of optical experiments. The primary constituents of the experimental design were: a Hewlett-Packard HP-87 used as the computer controller, the Tektronix OF235 Reflectometer, the Photodyne 22XLA Fiber Optic Multimeter and the 2275XQ Test Set. These devices were integrated through the General Purpose Interface Bus (GPIB) and software was developed to control the operation of the system. The system is capable of measuring many fiber parameters such as attenuation, index of refraction, loss characteristics as well as detecting and locating faults and breaks in single-mode fibers. In addition, the system possesses peripheral devices to store the data and to produce permanent records of the results.

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I. INTRODUCTION

Advances in any field of technology are dependent upon the ability to make accurate measurements on the objects being investigated. The field of optical fiber communication is no exception to this rule. The explosive growth in this area is due in great measure to the reduction in fiber loss to almost the theoretical limit. The intense effort to reduce fiber loss required the development of new techniques for making loss measurements. Those involved in this matter are well aware of the enlargement in cost and complexity of modern optical test systems over the years and, simultaneously, experienced technicians required to operate them are increasingly scarce.

When performing an experiment, an operator is involved with numerous time-consuming procedures, such as instrument settings, calibrations, and cable changeovers. Next, he or she needs to take readings and transcribe them for later analyses of the results. This measurement approach is reasonably good in many ordinary situations. However, in cases where increased accuracy is required, a manual measurement system is no longer the best choice. To cite an example, suppose one needs to perform an experiment in which the measured value is influenced by time-dependent stochastic variables. In order to reduce this influence it is necessary to average the results over a number of measurements taken at

different times and, depending upon the desired precision, vast amounts of data need to be handled. This is one of many situations where the use of an Automated Measurement System (AMS) can improve the reliability of the results and consequently facilitate drawing conclusions from an experiment.

With the advent of automation, the technology of measurements has assumed an almost completely different character. In the standards laboratories especially, measurements that formerly took hours, or even days, have now been reduced to minutes. As a consequence certain statistical tools have been made available to the metrologist. Indeed, the volume of data has become so large that the problem is now one of knowing how to best utilize and apply it.

The principal components of an AMS are the controller, interface bus, programmed instruments and peripherals, such as printers, mass storage units and graphic plotters. The controller is the dominant device on the system. It orchestrates the flow of information sending commands to other instruments, manipulates the acquired data in order to suit the experiment requirements and sends the processed data to the peripheral devices. The interface bus is the medium of communication between the devices in an AMS. It consists of a group of hardware lines connected to each instrument in the system through electronic modules acting like translators,

enabling different devices to share the same data structure and electrical wiring. The programmed instruments are the sensing equipment connected to the unit under test, whose operations are directly controlled by the controller. The peripheral devices are those through which the results of an experiment are available to the user.

The main purpose of this thesis was to document the implementation of an automated optical measurement system to be used as an educational tool in the Optical Electronics Laboratory of the Naval Postgraduate School.

The principal aspects involved in the design of a generalized automated system will be addressed and in a parallel manner the solutions encountered for this particular project will be discussed.

II. SYSTEM SPECIFICATION

The initial design phase for the system designer is to formulate a good definition of the system needs. This is required in order to establish a criterion of decision in the analysis of the design solutions. Depending on the expected profits and also on the funds allocated for the project, the system can be planned comprehensively or may just grow, with units added as the need arises or other conditions arise.

The bulk of this chapter comprises the background information about an automated system, gives a general view of the facts that should be considered when specifying such a system, and describes each device used in this project.

A. THE INTERFACE BUS

One of the main concerns of the potential user of an automated system is the interface scheme between the instruments. Typical questions are as follows: What will serve as a communications link to interconnect the controller and peripherals? What is the correct connector configuration? Will the instruments and connectors be compatible? What logic levels and convention should one use? How does one control the timing of logical signals? These questions and many more have plagued system designers for many years. The obvious solution

to the interface dilemma required a monumental effort of standardization among instrumentation manufacturers. [Ref. 1]

This section provides a general introduction to the GPIB and its structure leading to a more detailed examination of the bus specification, its cabling, hardware and finally its operation. Additionally, the section gives information about the interface commands and capabilities.

1. Introduction to the GPIB

An interface system specification optimized for the interconnection of programmable instrumentation must contain many vital communication capabilities if it is to interconnect independently manufactured products. It should be provided at a reasonable cost, with a high degree of compatibility and flexibility to apply to a wide range of products. Two IEEE[1] Standards have been developed to facilitate the design, manufacture, and use of instrumentation destined to be assembled in small systems:

- ANSI/IEEE Std. 488-1978, IEEE Standard Digital Interface for Programmable Instrumentation.
- ANSI/IEEE Std. 728-1982, IEEE Recommended Practice for Code and Format Conventions.

The basic objectives of the IEEE Std. 488-1978 are:

- Specify a system that is easy to use, but has all of the terminology and the definitions related to that system precisely spelled out so that everyone uses the same language when discussing the GPIB.

[1] Institute of Electrical and Electronics Engineers.

- Define all of the mechanical, electrical, and functional interface requirements of a system, yet not define any of the device aspects (they are left up to the instrument designer).

- Permit a wide range of capabilities of instruments and computer peripherals to use a system simultaneously and not degrade each other's performance.

- Allow different manufacturers' equipment to be connected together and to work together on the same bus.

- Define a bus that allows asynchronous communication with a wide range of data rates.

- Define a low-cost system that does not require extensive and elaborate interface logic for the low-cost instruments, yet provides higher capability for the higher-cost instruments if desired.

2. The Bus Structure

The GPIB comprises a plug-connected cable generally employing a total of 24 wires, seven used for signal ground return, 16 for signals proper and one (usually braided) main ground return, which links the chassis/frames of the instruments on the bus. [Ref. 2]

By incorporating the complex interface functions in the equipment to be connected, the interface cable can be entirely passive in nature. The cables connect in parallel all instruments to the bus. The connectors used are normally stackable, allowing easy loom formation without recourse to inverse soldered connections or other complications found on other connection systems. [Ref. 3]

The bus can be best understood by examining each of the above characteristics from the viewpoint of a general microcomputer I/O bus.

a. Bus Length

A maximum inter-unit cable length of 4 m is specified with a total connected length of not more than 20 m. It is possible to add bus extenders which either through buffering or, more commonly, by data conversion can take the bus to almost unlimited lengths. A bus-to-serial data converter could, via modem, be used to remotely control instruments via the telephone network. Optical fiber transmission units are also available as extenders. [Ref. 3]

b. Data Rate

Data rates of 250k bytes/s are considered the maximum for a normal full 20 m cable bus system used with logic drivers of the open collector type. The use of tri-state Schottky logic can increase the rate. Theoretically 1M byte/s is attainable with a maximum cable length of 15 m. This target also necessitates standard logic loads at one meter maximum cable intervals, together with terminal line input capacitances of 50 pF or less. Generally, standard loads are specified at 2 m intervals with an associated input capacitance limit of 100 pF. [Ref. 3]

The fastest data rates can only be achieved when, in addition to the above considerations, the instruments

themselves can operate at these rates. This includes the acceptance speed of the controller or listener. Most microcomputer systems utilize peripherals of differing operational rates, such as floppy discs at 31k or 62k bytes/s, tape cassettes at 5k to 10k bytes/s, and cartridge tapes at 40k to 80k bytes/s. In general, the only devices that need high speed I/O are the hard discs, operational at 781k bytes/s [Ref. 1]. Certainly the 250k bytes/s data rate that can easily be achieved by the GPIB is sufficient for microcomputers and their peripherals, and is more than needed for typical analog instruments that take only a few readings per second.

c. Byte Oriented

The byte transfer is almost universal in I/O applications; even 16-bit and 32-bit computers use byte transfers for most peripherals. The byte matches the ASCII code for characters and is an integral submultiple of most computer word sizes.

d. Interrupt Driven

Many types of interrupt systems exist, ranging from complex, fast, vectored/priority networks to simple polling schemes. The main tradeoff is usually cost versus speed of response. The GPIB has two interrupt protocols to help span the range of applications. The first is a single service request (SRQ) line that may be asserted by all interrupting devices. The controller then polls all devices to determine

which one wants service. The polling mechanism is well-defined and can be easily automated. For higher performance, the parallel poll capability in the IEEE 488 allows up to eight devices to be polled at once. Each device is assigned to one bit of the data bus. This mechanism provides fast recognition of an interrupting device. A drawback is the frequent need for the controller to explicitly conduct a parallel poll, since there is no equivalent of the SRQ line for this mode.

e. Direct Memory Access (DMA)

In many applications, no immediate processing of I/O data on a byte-by-byte basis is needed or wanted. In fact, programmed transfers slow down the data transfer rate unnecessarily in these cases, and higher speed can be attained using DMA. With the GPIB, one DMA facility at the controller serves all devices. There is no need to incorporate complex logic in each device.

f. Asynchronous Transfers

An asynchronous bus is desirable so that each device can transfer at its own rate. However, there is still a strong motivation to buffer the data at each device when used in large systems in order to speed up the aggregate data rate on the bus by allowing each device to transfer at top speed. The GPIB is asynchronous and uses a special 3-wire handshake whose states and timing patterns control the data byte transfers.

3. The Interface Operation

The operation of the bus can be understood with the description of the interface functions. To describe the interface functions, it is convenient to use terms appropriate for communication between human beings: talkers and listeners. In the bus context, a "talker" implies that the device is enabled to send data over the bus. Similarly, "listeners" are those devices enabled to receive data over the bus. In addition, a "controller" is required to designate which device is to talk and which device(s) are to listen. A controller also is capable of sending special types of data to all devices connected to the bus and receiving status data from other devices. [Ref. 1]

a. The Data Lines

Eight bidirectional data lines are used for data transfer. The information is transmitted in the form of a sequence of 8-bit characters. The ASCII seven-bit code is generally used with the eighth bit employed for parity checking. However, other encoding techniques may be utilized to compress information on these 8 lines. [Ref. 4]

The data lines are coded DIO (Data In/Out) and are numbered DIO1-DIO8. The data form is called bit parallel, byte serial, i.e., each byte appears as parallel bits on the data lines; the complete bytes are sent sequentially.

The data lines carry either interface messages or device dependent data, such as measurement readings. The distinction is established by the controller.

b. Handshake Operation

Data transfer on the bus is accomplished using an interlocked handshake sequence such that correct transfer is achieved despite widely varying data handling speeds for devices. This is the "handshake" system which can operate asynchronously allowing "fast" and "slow" devices to work together on the bus, with the data transfer rate being that of the slowest device currently in communication. A printer is an example of a listener with a slow data rate. However, when it is not being addressed and is thus quiescent on the bus, the data rate automatically rises to the speed of the next slowest device addressed. [Ref. 3]

The handshake operation (Fig. 1) is based on three signal lines. The sequence begins with the controller having released the DAV (DatA Valid) line high, indicating "invalid data". The listeners, previously addressed, then set NDAC (Not Data ACcepted) lines low to signal "unaccepted data". The controller then checks the NDAC line and once this line is low, meaning that no device is busy accepting data, the data byte appears on the data bus and transfer can begin. When ready to accept data, the listeners set NRFD (Not Ready For Data) high and once this is sensed by the talker, it replies,

releasing the DAV line low, signalling data valid. Data transfer now takes place; the controller signals the end of the byte by releasing the DAV line to high. Eventually all the listeners signal "data accepted" when the last of them finally releases the NDAC line to high. Both the NDAC and NRFD lines are wired-OR functions such that they can only be released when all units connected have released.

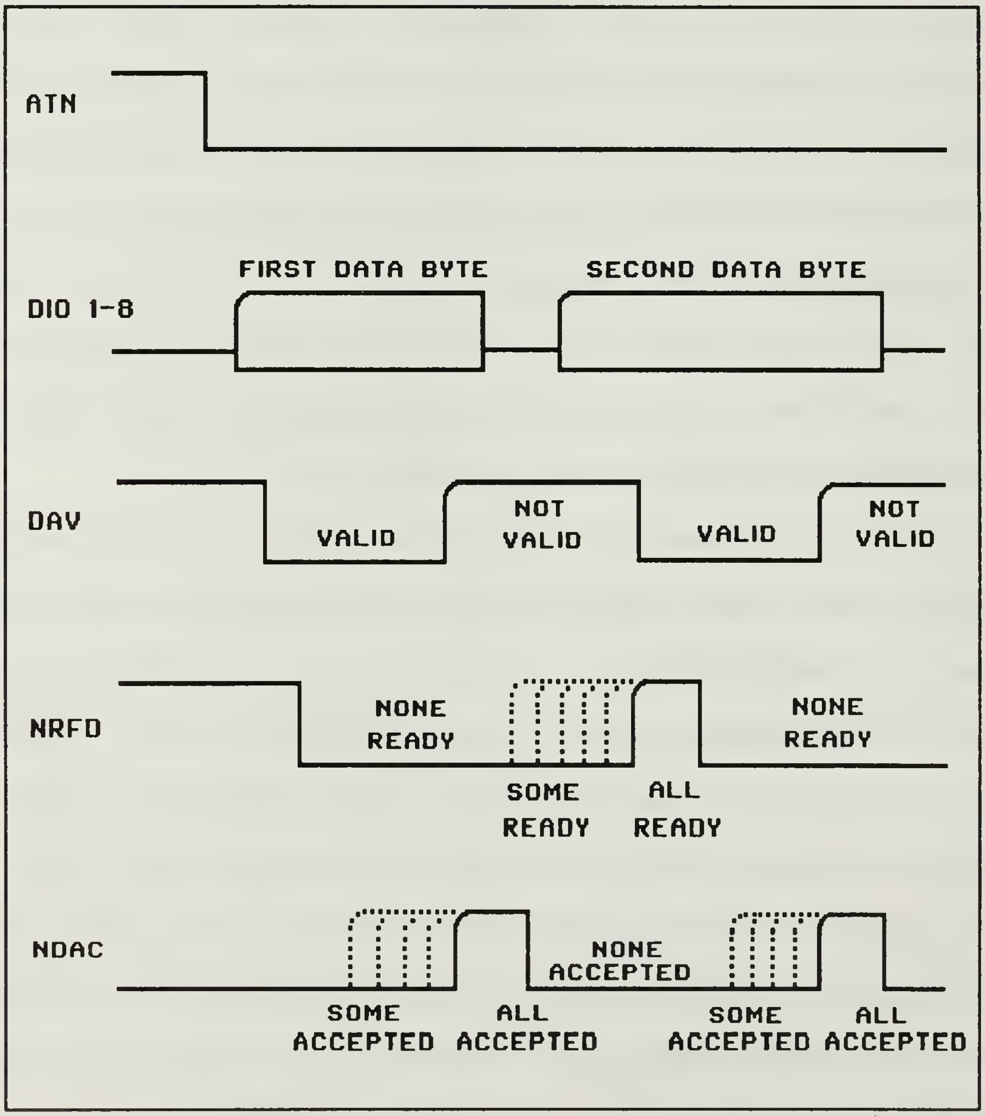

Figure 1. Handshake routine timing sequence (After Ref. 3.)

c. Interface Management Lines

Five signal lines are allocated to manage an orderly flow of information across the interface: [Ref. 4]

- ATN (ATtentioN) is used by the controller to specify whether information on the data bus is to be interpreted as an interface control message or as device-dependent data.

- IFC (InterFace Clear) is used to place the interface system in a known quiescent operating state, halting activity on the bus.

- SRQ (Service ReQuest) is used by a device to indicate the need for attention and to request an interruption of the current sequence of events.

- REN (Remote ENable) is used by the controller to enable devices to respond to program control when addressed to listen.

- EOI (End Or Identify) is used to indicate the end of a multiple byte transfer sequence or, in conjunction with ATN, to parallel poll devices for their status on the bus.

4. The Interface Commands

When the ATN line is set "ON", all devices on the bus release control of their interfaces and remain in a "listen" mode awaiting controller commands. These commands are defined in several groups: Universal, Addressed and Unaddressed.

The ability to respond to each class of command depends upon whether or not that device has the corresponding capability implemented on its interface.

a. Universal Commands

Universal commands cause every instrument to respond to it at any time, regardless of address. Interface Clear and Remote Enable are examples of universal commands.

b. Addressed Commands

Addressed commands are similar to the universal commands but affect only those devices whose addresses were issued by the controller. Examples of these are: Selective Device Clear, which returns the selected devices to a predetermined state and Go to Local, which returns responding devices to panel control.

c. Unaddressed Commands

Unaddressed Commands are used to partially cancel a previously addressed system condition. They are just two commands: Unlisten, which clears the bus of listeners and Untalk, which unaddresses the present talker on the bus.

5. Interface Capabilities

Interface capabilities are predefined functions which could be designed into a GPIB device. The designer is given the capability to select the particular set of interface functions necessary to fit the particular device application area.

a. Message Concepts

Devices which communicate along the interface bus are transferring quantities of information. The transfer of

information can be from one device to another device, or from one device to more than one device. These quantities of information can easily be thought of as "messages".

The messages can be classified into twelve types. The HP-87 computer, used in this project, is capable of implementing all twelve types of interface messages. The following list gives the twelve message types for the GPIB: [Ref. 12]

- The Data Message. This is the actual information which is sent from one talker to one or more listeners along the interface bus.

- The Trigger Message. This message causes the listening device(s) to perform a device-dependent action when addressed.

- The Clear Message. This message causes either the listening device(s) or all of the devices on the bus to return to their predefined device-dependent states.

- The Remote Message. This message causes listening devices to switch from local front-panel control to remote program control when addressed to listen.

- The Local Message. This message clears the Remote Message from the listening device(s) and returns the device(s) to front-panel control.

- The Local Lockout Message. This message prevents a device operator from manually returning the device to local (front-panel) control.

- The Clear Lockout/Local Message. This message causes all devices on the bus to be removed from Local Lockout and revert to Local. This message also clears the Remote Message for all devices on the bus.

- The Request Service Message. A device can send this message at any time to signify that the device needs some type of interaction with the controller. This message is cleared by sending the device's Status Byte Message if the device no longer requires service.

- The Status Byte Message. A byte that represents the status of a single device on the bus. Bit 6 indicates whether the device sent a Request Service Message, and the remaining bits indicate operational conditions defined by the device. This byte is sent from a talking device in response to a serial poll operation performed by a controller.

- The Status Bit Message. A byte that represents the operational conditions of a group of devices on the bus. Each device responds on a particular bit of the byte thus identifying a device-dependent condition. This bit is typically sent by devices in response to a parallel poll operation. The Status Bit Message can also be used by a controller to specify the particular bit and logic level that a device will respond with when a parallel poll operation is performed. Thus more than one device can respond on the same bit.

- The Pass Control Message. This transfers the bus management responsibilities from the active controller to another controller.

- The Abort Message. The system controller sends this message to unconditionally assume control of the bus from the active controller. This message terminates all bus communications (but does not implement a clear message).

These messages represent the full implementation of all GPIB system capabilities. Each device in a system may be designed to use only the messages that are applicable to its purpose in the system. It is important for the user to be aware of the GPIB functions implemented on each device in an automated system to ensure the operational compatibility of the system.

B. COMPUTER CONTROLLER

The choice of a controller is an important step in the specification of an automated system. Many factors must be considered, including reliability, programming requirements, and speed of execution. This section provides a general view of each of these factors and gives an overview of the computer controller used in this design.

1. Reliability

Reliability is one of the highest priority factors when choosing the controller for an AMS. The investment in a computer is not just its initial cost but also its life-cycle cost. This includes repair and maintenance which can be very high relative to ordinary laboratory instruments. Furthermore, the station under control has an overall cost, including software, whose return is based on utilization. When the application is in the production area, the lost production due to failure of a test station in the absence of a replacement controller can quickly exceed the cost of the controller itself. Therefore, this aspect of the computer controller specification has a big influence in the choice of the system controller. [Ref. 1]

2. Programming Requirements

A major factor in software cost is the quality of the controller program language with respect to the bus. [Ref. 3]

From the test engineer's viewpoint, programming in machine code is unnecessarily difficult and the resulting program is generally unreadable by anyone else. It is well worth examining the program-generation side of a controller carefully and making a realistic estimate of software versus hardware costs [Ref. 3]. Programming requirements are usually minimized by the use of high-level languages such as BASIC or hybrids, which combine the features of existing languages such as BASIC, FORTRAN, ALGOL and PL/I.

Professional computer programmers often fail to understand why test engineers almost universally use BASIC for GPIB programming. The reason is that test development engineers are not usually programmers and, therefore, they benefit from a language which is easy to learn. The major advantage of using BASIC is that, in contrast to many other compiled languages, it is an interpretive interactive medium. During the design of a test routine it is vital to be able to try out and sequence program instructions line by line. BASIC allows this step-by-step process, thus greatly aiding the analysis of GPIB problems. Bus commands entered on the keyboard may be sent directly and immediately to an instrument to verify the correct response to a trial instruction.

Areas where the program language enhancement can be very helpful include flexible handling of data formats. An ability to access commonly used subroutines by name is also

helpful. Where various block codes are used for data, error trapping routines aid reliability. At the computer level, operator conveniences such as a good display, fast editing facilities and the like are also important. [Ref. 3]

3. Speed of Execution

Speed of execution, allied with processing power, is often mistakenly understood as the prime performance factor. Clearly in a given application where a particular test installation is performing a test cycle in, say, 20 minutes and substitution of a more powerful controller provides a 5 minute saving, the productivity is enhanced by 25%. More important than high speed or large memory capacity is the internal hierarchy of the controller and how quickly it can service its I/O ports. Cases have been known of powerful minicomputers provided with control I/O facilities, including GPIB, where the I/O handling is unacceptably slow, representing a major loss in speed for the system. Generally, the more interfaces in use, the slower the system runs, so multiple interface facilities on controllers should be viewed with this in mind. The quality of GPIB-port handling is also important and some of the large general-purpose computers as well as certain add-on-adapters to GPIB are clumsy or incomplete in their design. [Ref. 3]

Features such as DMA are important, as well, in allowing large data block transfer to a mass storage or memory while servicing other bus commands.

Finally, it must be conceded that, if a large high level language is an important factor, a powerful controller with large memory is required to handle that language and it is in this context that high speed of the more advanced controller falls into place.

4. The HP-87 as the System Controller

The project undertaken here used an HP-87 as the computer controller. The HP-87 is a member of the Series 80 group of Hewlett-Packard's personal computers. It has 128k bytes of built-in user memory with the capability to expand to 640k bytes, a 48k ROM operating system, and 16k of display memory. The plug-in CP/M module extends the HP-87 system by adding a Z-80 processor and 64k bytes of dedicated RAM (CP/M user memory). The CP/M system also gives ready access to other computer languages, including PASCAL and FORTRAN.

The HP-87 provides powerful programming features, high-resolution graphics generation, a variety of optional interface modules, and computer's integrated interfacing capabilities allowing the computer to participate in a broad range of input/output operations.

For this project, the most important feature provided by the HP-87 is its built-in GPIB interface which supports a

wide variety of operations, enabling communication and control of test and peripheral devices without requiring any bus adaptation. With all these features, the HP-87 is a very attractive solution for the control of small automated systems.

Detailed information about the HP-87 can be found in Ref. 5.

C. PERIPHERALS

In the context of automated measurement systems, peripherals are those devices readily joined to the system to ease the tasks of data storage and documentation.

The competitive nature of the computer market, particularly with respect to peripherals, has resulted in reduced pricing for many of these devices. The peripheral designers have come up with new ways of handling and processing information; many inexpensive dot matrix printers are available with quite useful graphic facilities. Vector plotters are unrivalled where high-quality graphs suitable for publication are required. In their current "intelligent" forms, they can also annotate their graphs in a variety of alphanumeric styles.

When the controller chosen for a system has no permanent built-in data or program storage, as is the case of the HP-87, it is necessary to have a mass storage device. The type

of mass storage to be used depends on the kind of application but where programs involving fast storage of a large data field is the case, disc units are essential.

1. Mass Storage

The mass storage device used in this project is the HP 82901M/S Flexible Disc Drive from Hewlett-Packard. It contains two disc drives and up to 286.72k bytes of information can be stored on each.

More information about the mass storage can be found in Ref. 6.

2. Plotter

The plotter used in this project is the HP 7470A Graphics Plotter from Hewlett-Packard. It is a vector plotter which produces high quality, multicolor graphics plots on two sizes of drawing media. The multicolor graphics capability is provided by programmed or front panel selection of two pens. If additional colors are desired, the program can be temporarily halted to allow manual installation of additional pens. Seven different dashed-line fonts and symbol mode plotting provide additional trace identification capabilities.

The HP 7470A is implemented with the following GPIB capabilities:

- SH1 - Source Handshake capability
- AH1 - Acceptor Handshake capability
- T2 - Talker (Basic Talker, Serial Poll)

- L2 - Listener (Basic Listener)
- SR1 - Service Request capability
- RL0 - No Remote Local capability
- PP2 - Parallel Poll (Local configuration)
- DC1 - Device Clear capability
- DT0 - No Device Trigger capability
- C0 - No Controller capability

More information about the plotter can be found in Ref. 7.

3. Printer

The printer used is this project is the HP 82905B from Hewlett-Packard. It operates bidirectionally at the rate of 80 characters/s.

D. TEST DEVICES

The test devices constitute the instruments that will perform the data acquisition on the device under test. Their specification is dependent upon the measurement functions the system is supposed to perform. Therefore, when implementing an automated system it is good procedure to study the device data sheets as early as possible so that the acquisition capabilities of the test units can be analyzed and a better decision of purchase can be made.

This section will describe the features and applications of the test devices used in this project.

1. Fiber Optic Multimeter

The Photodyne Model 22XLA Fiber Optic Multimeter is the optical version of a digital multimeter, developed specifically for fiber optics applications. It provides for absolute measurements of all aspects of fiber optic systems, including light sources and emitters, photoreceivers, fiber cable transmission, connector and splice loss. [Ref. 8]

The 22XLA multimeter has the following features:

- Autoranging in dB over nine decades.
- Selectable 0.1 or 0.01 dB resolution.
- Selectable Mode: SINGLE head mode for absolute measurement and DUAL head mode for ratio measurements.
- SAMPLE/HOLD mode for performing measurements relative to an external reference light level.

In order to integrate the 22XLA multimeter to the system, it is necessary to use the Model 488XLI GPIB interface [Ref. 9] which has the following bus capabilities:

- SH1 - Source Handshake capability
- AH1 - Acceptor Handshake capability
- T3 - Talker (Basic Talker, Talk Only)
- TE0 - No Talker secondary address capability
- L0 - No Listen interface function capability
- LE0 - No Listen secondary address capability
- SR0 - No Service Request capability

- RL0 - No Remote Local capability
- PP0 - No Parallel Poll capability
- DC0 - No Device Clear capability
- DT0 - No Device Trigger capability
- E1 - Open collector bus drivers

2. Fiber Optic Test Set

The Photodyne Model 2275XQ Fiber Optic Test Set offers the highest performance in intelligent power meters for both fiber optic applications and general radiometry. [Ref. 10]

The Model 2275XQ Test Set has the following features:

- Maximum performance power meter (-80 to +36 dBm)
- Maximum accuracy-average reading power meter (±0.25 dB)
- Built-in 100 point data logger
- Built-in IEEE Std. 488 Interface
- Works in all fiber optic wavelengths
- Works with all fiber optic connectors

The GPIB capabilities of this test set are:

- SH1 - Source Handshake capability
- AH1 - Acceptor Handshake capability
- T6 - Talker (Basic Talker, Serial Poll, Unaddresses if MLA)
- L4 - Listener (Basic Listener, Unaddresses if MTA)
- SR1 - Service Request capability
- RL1 - Remote/Local capability
- DC1 - Device Clear capability

- DT1 - Device Trigger capability
- E1 - Open collector bus drivers

3. Fiber Optic Time Domain Reflectometer

The Tektronix OF235 Time Domain Reflectometer is an optical fiber tester that is capable of measuring loss characteristics, and detecting and locating faults in single-mode fibers.

The OF235 applies a pulse of energy to the fiber to be tested. When the pulse is traveling through the fiber, some energy is scattered back to the OF235. These reflections are processed and displayed on the cathode ray tube (CRT), where distance and loss measurements can be made using a marker technique. [Ref. 11]

The test characteristics of the OF235 Reflectometer are:

- Distance measurements readout range: 0 to 99.9 km
- Readout resolution: 1 meter
- Index of refraction: 1.400 to 1.599
- Distance accuracy: ±0.05% (±1 meter)
- Loss measurement range: -25dB to +25dB

The GPIB capabilities of this reflectometer are:

- SH1 - Source Handshake capability
- AH1 - Acceptor Handshake capability
- SR1 - Service Request capability
- RL1 - Remote/Local capability

- DC1 - Device Clear capability
- DT1 - Device Trigger capability
- T5 - Talker (Basic Talker, Serial Poll, Talk Only, Unaddresses if MLA) if GPIB switch is not set to "TON"
- T3 - Talker (Basic Talker, Talk Only) if GPIB switch is set to "TON"

E. SYSTEM CONFIGURATION

The system implemented in this project has the configuration shown in Figure 2.

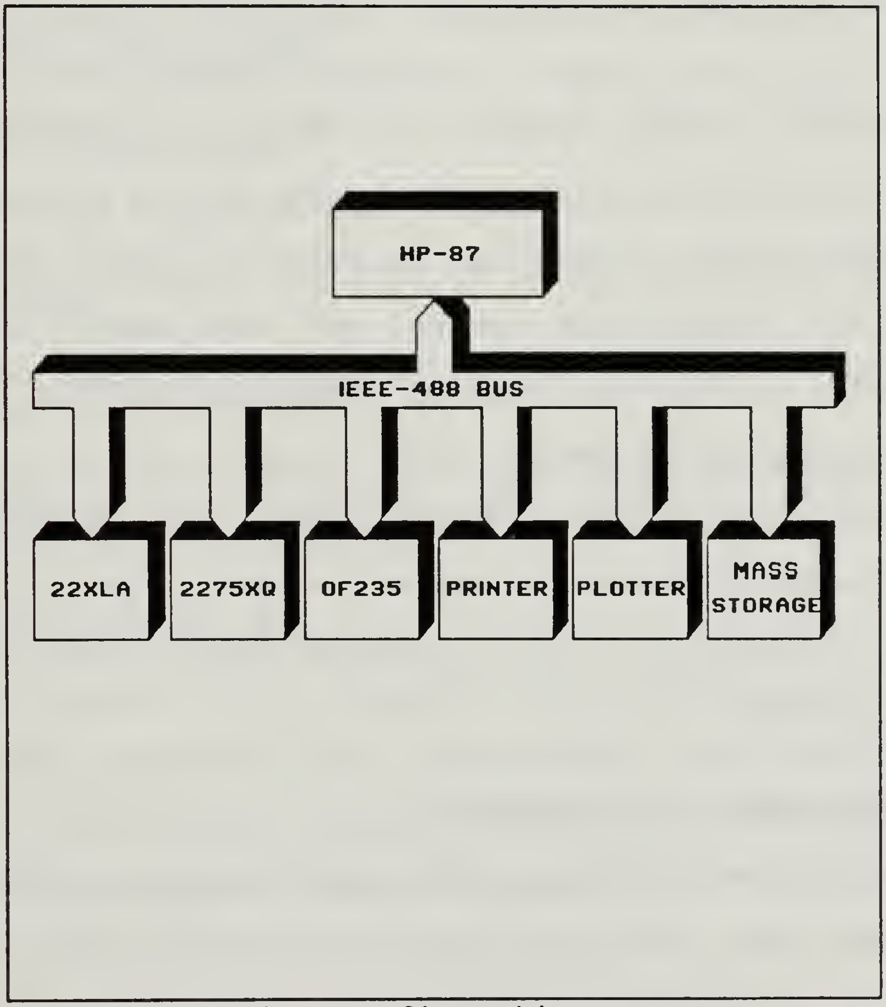

Figure 2. System configuration

III. PROGRAMMING THE SYSTEM

Automated system devices are programmed by means of data messages sent over the bus from the controller. The data messages are comprised of two parts, the address command and the program information. The address command identifies the devices as "talkers" or "listeners"; the program information contains codes which control various programmable functions of the talker or listener. These codes are assigned by the manufacturer and are included in the instrument manuals. One program line may contain the address command plus all of the programming codes required to put an instrument in a particular operating mode. The syntax of the data message is dependent on the controller as well as on the test device; therefore, successful control of instruments requires a knowledge of both the computer controller and the instrument programming requirements.

This chapter will present general considerations about programming an automated system via the GPIB and will give detailed examples of data messages used in this particular application.

A. PROGRAMMING CONSIDERATIONS

Writing an automated measurement system program consists of combining standard-program statements with instrument

programming instructions. The main steps in producing a preliminary AMS program are as follows:

- Define the measurement task;
- Examine the range and quality of parameters to be measured;
- Determine the accuracy requirements;
- Select a system controller and appropriate programmable instrumentation;
- Interface the instrument to the controller and integrate the system;
- Assign address codes to all programmable instruments;
- Determine the magnitude, function, and sensitivity of all analog outputs used;
- Provide interface circuitry for any binary-coded decimal (BCD) outputs used;
- Determine a logical test sequence;
- Develop software routines to perform each specific test function;
- Unite the test routines in the proper sequence and complete the program;
- Insert conversational prompting to be displayed by the controller to instruct the operator when manual adjustments are required.

B. CONTROLLING THE BUS

This section will present the development of some programming routines used in this project. Each routine will document the necessary parameters that must be sent by the controller to properly control the bus.

1. Address Assignment

As mentioned in the previous chapter, each device in the system has an address for its identification. In order to set up a device for the desired address, it is necessary to configure the GPIB switch found in each device to the corresponding position. The list of addresses and the corresponding GPIB switch positions used in this project are given in Table I.

TABLE I DEVICES ADDRESSES

DEVICE	ADDRESS	GPIB SWITCH
HP-87	721	1110101100
488XLA	702	00000010
2275XQ	706	00110
OF235	704	11000100
PRINTER	701	000001
PLOTTER	705	1000101
M. STORAGE	700	000

2. Using the Interface Commands

The interface commands were presented in the previous chapter. Here it will be shown how BASIC statements can be used to send them through the bus. Table II summarizes the interface commands and lists the HP-87 BASIC statements that

send each of the interface commands through the bus. Each addressed command statement assumes a primary address of 2.

TABLE II INTERFACE COMMANDS

COMMAND	BASIC STATEMENT
REN	REMOTE 702
GTL	LOCAL 702
IFC	ABORTIO 7
DCL	CLEAR 7
GET	TRIGGER 702

a. Remote

Typically the first operation necessary for GPIB systems is to program all devices for remote operation via the bus. The 2275XQ Test Set and the OF235 Reflectometer are capable of manual front panel operation or of remote bus operation. Not all instruments have this capability implemented in their interface, as is the case of the 22XLA multimeter. The remote mode of operation for a device is selected by setting the REN line and addressing the device to listen. In this system, the REN line is set by the computer when power is turned on, the command "Reset" is used, or the "Remote" statement is executed. Addressing the device to listen is performed by executing any statement which includes

that device's listen address. For instance, to place the 2275XQ and the OF235 under remote control, the statement

REMOTE 706,704

could be used. Setting REN true without addressing (such as when the computer is turned on) will put the devices in the remote mode only when an addressed command is received.

This remote mode can be reversed by means of the Return-to-Local switch located in the front panel of the OF235 Reflectometer or by action in any of the front panel commands of the 2275XQ Test Set.

To prevent any of the system devices from being unintentionally returned to local operations from the front panel, a "Local Lockout" or LLO message must be sent. The example cited above now looks like this:

REMOTE 706,704

LOCAL LOCKOUT 7

Now the two instruments are set up for remote control, with the front panel disabled.

b. Go to Local

The "Go to Local" command is used to take the instrument out of the remote mode. The GTL command sequence

is automatically sent to the 2275XQ Test Set by the HP-87 with the following statement:

```
LOCAL 706
```

Once this command is sent, both the "Remote" and "Local Lockout" indicators turn off and the front panel controls are no longer locked out. The "Remote" and "Local Lockout" modes can be restored by readdressing the 2275XQ Test Set to listen. The "Remote" command would accomplish this.

c. Interface Clear

The "Interface Clear" command is sent by the controller to set the devices to the Talk and Listen idle states. At the same time, any function in progress will be aborted. The 2275XQ Test Set, after the "Interface Clear" command, will reset to the DC mode, autoranging ON, dBm units, and the current Cal Wavelength, since this is its power-on state.

To send the IFC command, the controller needs only set the IFC line true. The following BASIC statement will accomplish this:

```
ABORTIO 7
```

After the "End Line" key is pressed, the 2275XQ Test Set will abort any current function and will normally be displaying measurement data while awaiting its next command.

d. Device Clear

The "Device Clear" command resets all devices equipped to respond to a DCL command to the Power-On state. The devices will not respond to the DCL until the current function in progress is completed. If the user wishes to abort, he should first issue an "Interface Clear" command. The following BASIC statement will accomplish the "Device Clear" command:

```
CLEAR 7
```

If the user does not need to "Clear" all devices (equipped with the Device Clear capability) in the bus, a "Selective Device Clear" command should be issued. The following statement will do this for the case of the OF235 Reflectometer:

```
CLEAR 704
```

e. Group Execute Trigger

The "Group Execute Trigger" (GET) command is used to synchronize data sampling from one device with other

devices on the bus. It is used in conjunction with the "Trigger" command, which controls the stimulus to be used to start an A/D conversion (sampling).

In the 2275XQ Test Set, for instance, triggering may be done in two basic ways: in a continuous mode, a single trigger command is used to start a continuous series of readings; in a one-shot trigger mode, a separate trigger stimulus is required to start each conversion.

The 2275XQ Test Set has four trigger commands as follows:

- TRIGGER 1 Continuous after Talk
- TRIGGER 2 One-Shot on Talk
- TRIGGER 3 Continuous after GET
- TRIGGER 4 One-Shot on GET

In the "Trigger 1" and "Trigger 2" modes, triggering is done by addressing the 2275XQ Test Set to talk. In the "Trigger 3" and "Trigger 4" modes, a GET command provides the trigger stimulus. The following statement will place the instrument into the Data Store mode and "Start-on-GET" trigger mode:

```
OUTPUT 706; "TRIGGER 4"
```

When the "End Line" is pressed, the 2275XQ Test Set will hold the last reading. To trigger for a measurement, the instrument will be waiting for a GET command (so that it can be

synchronized with other equipment in the measurement setup) as follows:

TRIGGER 706

The preceding example uses the command "Output" to place the instrument in the appropriate trigger mode. This command is covered in the next subsection.

3. Device Dependent Command Programming

Device Dependent Commands are used to program the devices to their various operating modes. Each command is made up of a short ASCII word followed by one or more numbers designating specific parameters.

If an illegal command or command parameter is present within a command string, the devices may react in any of the following ways, depending upon their capabilities:

- Ignore the entire command string,
- Display appropriate front panel error messages,
- Set certain bits in the status byte,
- Generate an SRQ if programmed to do so.

A Device Dependent Command is generally accomplished by means of simple "Output" statements directed to the device to be programmed. For instance, suppose the OF235 Reflectometer is to work with the Index of Refraction set to 1.400. The following statement would execute this:

```
OUTPUT 704; "IR 1.400"
```

Once the system devices are programmed for operation, it is possible to take readings from them. This is accomplished by means of the "Enter" command, which addresses the specified device and accepts data from it. For example, to take an optical power reading from the 22XLA Multimeter and place it into a string variable A$, the following statement could be used:

```
ENTER 702; A$
```

When using the device-dependent commands, the user should read the device's operator manual carefully to avoid difficulties. The 2275XQ Test Set, for instance, has its power-on values stored in a non-volatile RAM. These power-on values can only be changed when the "WE" switch located on the rear panel is "ON" and the appropriate command is executed. It does not matter whether the command originated from the front panel or the GPIB. Since the "WE" switch position is not a necessary part of these functions, no error code is ever generated. Therefore, the user must set the "WE" switch "ON" only if he wishes these parameters to be changed.

4. Using Program Loops

The "For" and "Next" commands are used to enclose a series of statements, enabling the user to repeat those statements a specified number of times. The following program sets the 2275XQ to measure optical power in absolute dBm units, to take 20 readings and to display them on the CRT.

```
10 CLEAR  ! CLEAR CRT
20 REMOTE 706  ! SET UP FOR REMOTE OPERATION
30 OUTPUT 706; "DBM"  ! SET UP FOR dBm UNITS
40 FOR I=1 TO 20   ! START LOOP
50 ENTER 706; A$   ! PLACE READING INTO A VARIABLE
60 DISP A$   ! DISPLAY READING ON CRT
70 NEXT I   ! END LOOP
80 END
```

5. Handling Service Requests

The cause of a service request is device-dependent, that is, different devices have different reasons for requesting service. For instance, a printer may request service because it has just run out of paper, or an instrument like the OF235 Reflectometer may request service because the argument of one of its commands is out of range, or a device may request service just because it has accomplished a job and

is ready for the next. Regardless of the reason, once a request has been received, two actions must be taken:

- Locating the device which requested service, and
- Determining the reason for the device's request.

A device needs to be in the SRQ mode to be able to generate a service request. This is done executing the SRQ command as shown in the following statement:

```
OUTPUT 706; "SRQ 1"
```

The program has to provide the way to find out if a service request has been received. The following statement performs a status check to accomplish this:

```
STATUS 7,2;S
```

With the execution of this statement the bits contained in the Status Register SR2 of the HP-87 interface will be placed into variable S and, if bit 5 is set to 1, it will indicate that an SRQ has been received.

The next step is to identify which device has requested service. In order to do that the controller has to conduct a polling to determine the operating status of each device that supports a poll function. There are two processes for doing this, serial poll and parallel poll. In the case of

serial poll, the controller reads the status byte of each of the devices expected to have requested service. Bit 7 of the status byte is set to 1 if the device requested service or it is set to 0 if it did not. The remainder of the bits in the status byte can be used to indicate the reason for the service request and are totally device dependent. The statement below may be used to read the status byte of the 2275XQ Test Set:

```
S=SPOLL (706)
```

In a parallel poll each device is assigned one of the DIO lines for identification purposes. This is configured within each bus device. The controller reads DIO1 through DIO8 all at once to determine which device(s) requested service. In practice the number of devices addressed may be extended beyond eight by sharing the DIO line codes with more than one device when so required. The following statement conducts a parallel poll in the HP-87 interface bus:

```
P=PPOLL (7)
```

The program below exemplifies the use of a service request due to completion of a function by the 2275XQ Test Set. It should be observed that the instrument will begin sampling and storing data every 5 seconds until 100 samples

are stored. The controller waits for the SRQ line to be set by the 2275XQ (what happens at the end of the data storing), performs a serial poll and displays the status byte bits on the CRT.

```
10 CLEAR
20 REMOTE 706
30 OUTPUT 706; "SRQ 1"  ! ENABLE SRQ MODE
40 REM "SAMPLE EVERY 5 SEC FOR 100 DATA POINTS"
50 OUTPUT 706; "STO 5,100"
60 STATUS 7,2; S  ! CHECK HP-87 INTERFACE STATUS
70 IF BIT (5,0) = 0 THEN 60  ! LOOP UNTIL SRQ ACTIVE
80 S=SPOLL  (706)  ! CONDUCT SERIAL POLL
90 DISP "B7 B6 B5 B4 B3 B2 B1 B0"
100 DISP
110 FOR I=7 TO 0 STEP -1  ! LOOP EIGHT TIMES
120 DISP BIT (S,I);  ! DISPLAY STATUS BYTE BITS
130 NEXT I  ! END LOOP
140 DISP
150 END
```

6. Handling Interface Problems

Generally when a GPIB device develops a problem, either it holds up the data transfer that it is involved in, or it sends an SRQ to the controller, or it does both. In the

last subsection it was presented how the controller might handle the service request, but suppose the device stops handshaking in the middle of a data transfer and at the same time it sends an SRQ. This event presents a problem to the computer because it cannot perform an end-of-line branch to service the SRQ. Why this is so becomes apparent when one considers the nature of an end-of-line branch: it does not occur until the current BASIC program line has been executed, and if an "Enter" or "Output" operation still is not completed, the bus is "hung". It cannot complete the transfer, and it cannot execute an end-of-line branch until the operation finishes. The computer can recover from an unsuccessful transfer, however, by using the "Timeout" capability provided for such a situation. [Ref. 12]

The computer is able to avoid a hung-up mode executing the "On Timeout" command. This command defines and enables an event-initiated branch to be taken when an I/O timeout occurs on the specified interface. The statement below executes this command assuming a branch to the subroutine number 1000:

ON TIMEOUT 7 GOSUB 1000

The command "Set Timeout" is used to set a handshake time limit before the timeout branch to occur. The following statement sets the handshake time limit to 1500 ms:

```
SET TIMEOUT 7; 1500
```

To cancel the event-initiated branches previously defined and enabled by an "On Timeout" statement, the "Off Timeout" command has to be used as shown below:

```
OFF TIMEOUT 7
```

The following program shows the sequence of operations necessary to provide a system with the capability of recovering from an eventual bus hang-up. In this example, the 2275XQ Test Set is programmed to take readings continuously until an eventual error occurs. If this error is capable of hanging the bus up, the program execution will branch to the timeout service routine. This routine will check the interface status, print the contents of Status Registers, conduct a serial poll to verify the type of error, inform the operator that a malfunction has occurred, and pause the program so that the problem can be analyzed. Once the problem is corrected, the program can continue taking readings as before.

```
10 CLEAR
20 DIM P(6)  ! RESERVE MEMORY FOR P
30 ON TIMEOUT 7 GOSUB 90  ! ENABLE TIMEOUT MODE
40 SET TIMEOUT 7; 1500  ! SET HANDSHAKE TIME LIMIT
```

```
50 OUTPUT 706; "TRIGGER 2"  ! ENABLE TRIGGER READINGS
60 ENTER 706; A$  ! TRIGGER AND READ
70 DISP A$
80 GOTO 60
90 FOR I=0 TO 6  ! START SERVICE ROUTINE
100 STATUS 7, I; P(I)  ! CHECK THE INTERFACE STATUS
110 PRINT "STATUS BYTE #"; I; "="; P(I)
120 NEXT I
130 S=SPOLL (706)  ! CONDUCT SERIAL POLL
140 LET X=0
150 DISP "B3 B2 B1 B0"
160 FOR K=3 TO 0 STEP -1
170 DISP BIT (S,K);
180 X = X + BIT (S,K)  ! CHECK FOR DEVICE ERROR
190 NEXT K
200 DISP
210 IF X <> 0 THEN 220 ELSE 240
220 DISP "2275XQ REPORTS AN ERROR"
230 BEEP @ PAUSE  ! INFORM OPERATOR
240 ON TIMEOUT 7 GOSUB 90  ! RESTORE ORIGINAL SERVICE ROUTINE
250 RETURN  ! CONTINUE TALKER READINGS
```

7. Power-On Check-Out Routine

Once the system is installed and has its power turned on, it may be of interest to the operator to verify that all

instruments are responding to the controller commands. A program similar to the one below can be used for this purpose. This program will check the status of the seven devices from address 700 to 706. This includes the devices integrated into this system.

```
10 CLEAR
20 SET TIMEOUT 7; 1000
30 ON TIMEOUT 7 GOTO 100
40 FOR I=0 TO 6
50 DISP "SPOLL DEVICE # ";I
60 S=SPOLL (700+I)
70 DISP "DEVICE ";I;" IS RESPONDING"
80 NEXT I
90 STOP
100 ABORTIO 7
110 DISP "DEVICE  ";I;" DOES NOT RESPOND"
120 GOTO 80
130 END
```

8. Converting Strings to Numbers

Sometimes it is difficult to read data returned from a test device because these data come into the GPIB as a string of numbers separated by commas. It is not possible to read this string of characters with a formatted read statement

to pull out the separate numeric values. This is the case of the command "Curve?" in the OF235 Reflectometer which returns 126 data points separated by commas. In order to convert this string of data into numbers that can be used in calculations, the command VAL should be used. The following statements give an example of how to use this command:

```
A$ = "2,5,4,10"  ! ASSIGNS STRING TO VARIABLE A$
VAL (A$[7])  ! READ THE NUMBER AT POSITION 7
```

After the execution of these statements, the number 10 (at position 7 in the string) is converted into a numeric value.

The following routine, used in this project to take readings from the OF235 Reflectometer, is an example of converting strings to numbers.

First, it opens a data file, reads waveform data points from the Reflectometer with the command "Curve?", converts the string into numeric values, places the converted numeric values into a data file, and closes it.

```
10 CLEAR
20 ASSIGN# 1 TO "CURVE:D700"  ! OPEN DATA FILE
30 DIM A$[1000]  ! RESERVE MEMORY FOR STRING
40 SHORT B(1000)  ! RESERVE MEMORY FOR NUMBER
50 OUTPUT 704; "CURVE?"  ! READ WAVEFORM POINTS
```

```
60 ENTER 704; A$  ! PLACE INTO MEMORY
70 FOR N=7 TO LEN (A$) STEP 6
80 B(N-6) = VAL (A$[N])  ! CONVERT INTO NUMBER
90 PRINT# 1 ; B(N-6)  ! WRITE TO DATA FILE
100 NEXT N
110 ASSIGN# 1 TO *  ! CLOSE DATA FILE
120 RETURN
```

9. Controlling the Plotter

The measurements in fiber optics undertaken in this project generally have output data to be plotted. Data can be plotted in a variety of ways, depending on the degree of sophistication required. A basic graph can be created using only these four steps:

- Set the graphic limits.
- Scale the plotting area.
- Draw and label the axes.
- Plot the data.

The data to be plotted have to be transmitted from the computer to the plotter. This data transference is typically accomplished using I/O statements as "Plot", "Print", "Print#", or "Output". The following routine is an example of how the HP7470A plotter can be controlled to plot the currently displayed waveform and settings of the OF235 Reflectometer. This routine uses some variables previously

defined in the set-up routine of the instrument. It is also assumed that the data to be plotted have been previously stored in a data file.

```
10 PLOTTER IS 705  ! SPECIFY THE PLOTTER
20 ASSIGN# 1 TO "CURVE:D700"  ! OPEN DATA FILE
30 PEN 2
40 LOCATE 9,122,10,89  ! LOCATE THE PLOTTING AREA
50 REM "ENTER DISTANCE FROM FIRST DATA POINT"
60 OUTPUT 704; "DIST? @ ENTER 704; DI
70 SCALE DI,DI+10*D,-(5*V),5*V  ! SCALE THE PLOTTING AREA
80 REM "SPECIFY DECIMAL POINT IN LABEL"
90 IF V=.25 THEN FXD 0,2 ELSE FXD 0,0
100 LGRID -D,V,DI,0,1,1  ! DRAW A GRID
110 REM "LABEL THE SET UP VARIABLES"
120 MOVE 10.2*D+DI,5*V @ LABEL "VERTICAL"
130 MOVE 10.2*D+DI,3*V @ LABEL "DIST/DIV"
140 MOVE 10.2*D+DI,V @ LABEL "PULSEWIDTH"
150 MOVE 10.2*D+DI,-V @ LABEL "INDEX OF "
160 MOVE 10.2*D+DI,-(1.4*V) @ LABEL "REFRACTION"
170 MOVE 10.2*D+DI,-(3*V) @ LABEL "FILTER"
180 MOVE 10.2*D+DI,-(5*V) @ LABEL "WAVELENGTH"
190 PEN 1  ! CHANGE PEN
200 MOVE DI+2.5*D,6*V @ LABEL "RETURN WAVEFORM ON OTDR"
210 MOVE 10.1*D+DI,4*V @ LABEL V; "dB/DIV"
```

```
220 MOVE 10.1*D+DI,2*V @ LABEL D; "m/DIV"
230 MOVE 9.5*D+DI,0 @ LABEL P1$
240 MOVE 10.1*D+DI,-(2*V) @ LABEL I
250 MOVE 9.7*D+DI,-(4*V) @ LABEL F$
260 MOVE 10*D+DI,-(6*V) @ LABEL "   1300nm"
270 MOVE 3*D+DI,-(6*V) @ LABEL "DISTANCE ALONG THE FIBER"
280 DEG @ LDIR 90  ! MAKE PERPENDICULAR LABEL"
290 MOVE -(.5*D)+DI,-(2.3*V) @ LABEL "RELATIVE POWER (dB)"
300 MOVE DI,0
310 FOR I=1 TO 126
320 READ# 1; P(I),Z(I)  ! READ DATA FILE
330 P(I)=25-P(I)
340 DRAW DI+D*I*10/126,P(I)  ! DRAW WAVEFORM
350 NEXT I
360 ASSIGN# 1 TO *  ! CLOSE DATA FILE
370 RETURN
```

IV. OPERATING THE SYSTEM

While it is the hardware that defines the performance limits of an AMS, the system utility and ease of use are defined by the software which drives it. The program developed in this project provides the basic capabilities that an automated system must have: data acquisition, data display, and storage capabilities. Many variations on this basic theme are possible. If desired, this program can be easily modified to implement a different approach.

This chapter describes how the program is organized and how it interacts with the system operator.

A. PROGRAM ORGANIZATION

The program was structured in a modular concept allowing the programmer to insert new subroutines whenever the need arises.

The CRT of the HP-87 provides visual interaction with the system operator, providing menu-driven conversational prompts to guide the test procedures and to inform when manual manipulations, such as "load the printer with paper", are required. The fact that the operator may be prompted by the computer to perform system adjustments does not necessarily imply that unskilled personnel may be designated to operate the system. Automated systems are just as susceptible to

malfunction and errors as manual systems, and an operator must have the ability to recognize incorrect test results when they occur. The indiscriminate acceptance of automatically-acquired data should be an unacceptable practice in any engineering environment.

B. PROGRAM HIGHLIGHTS

1. Starting Operation

All devices in the system must have their GPIB switches set to their addresses before having their power turned on. Since this system includes peripherals, they need to be switched on before the computer or a system reset should be performed so that the computer will be sure to recognize the existence of peripherals that are connected to the bus. A peripheral that is connected to the bus can have its power off without affecting the system operations, as long as more than 50% of the system devices have their own power on. For example, if there are three peripheral devices, two must have their power on; if there are two peripherals, both must have their power on.

The main program in this project is expected to be stored on disc ":DRIVE0" and it makes use of the "autostart" feature provided by the HP-87. That is, after power is turned on, the main program will automatically be loaded into the computer and executed.

2. Program Flowchart

In Figure 3 a program flowchart shows how the modules of the program interact as a whole.

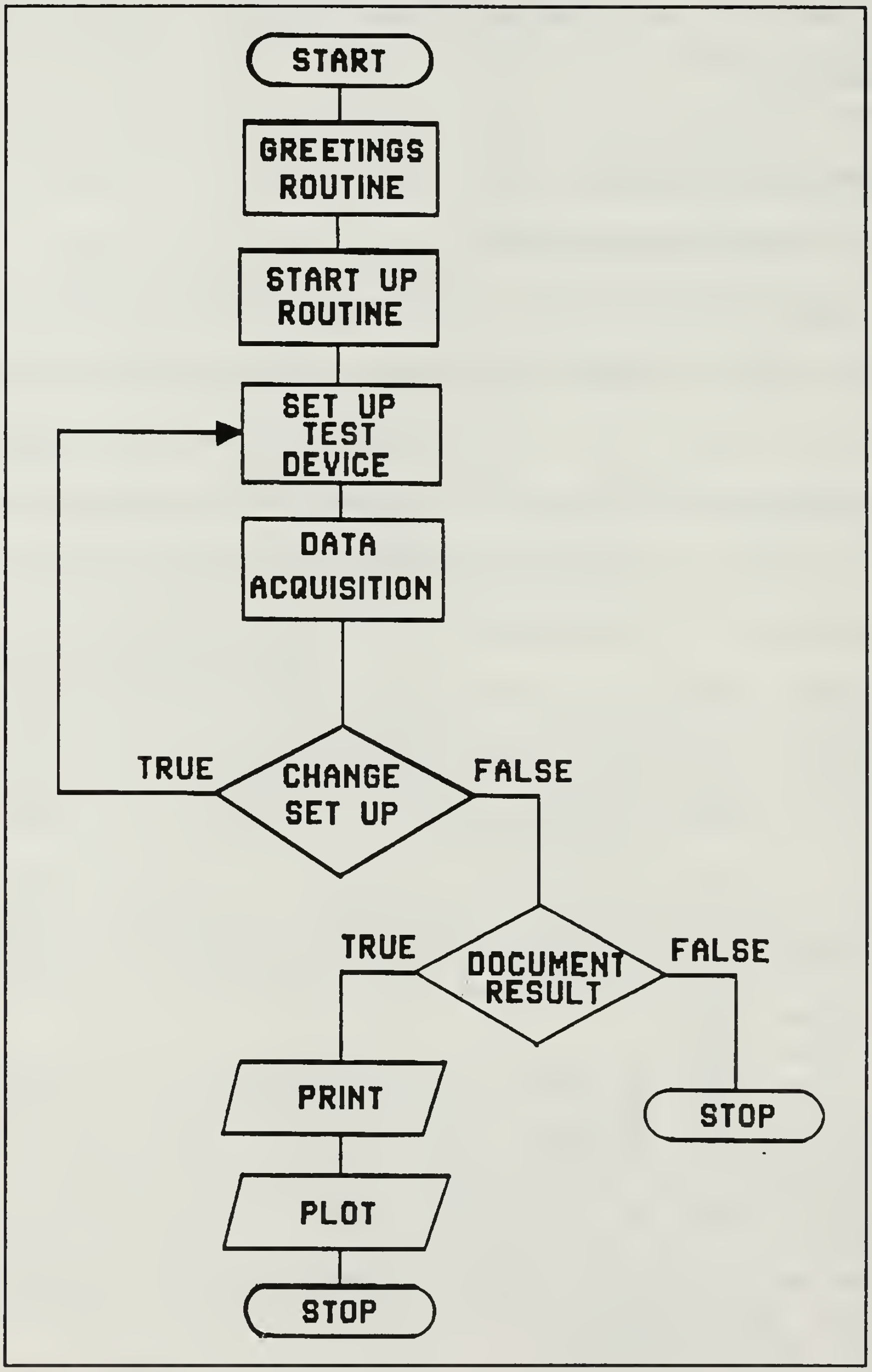

Figure 3. The program flowchart

3. Running the Program

The program begins by drawing a box for the system greetings on the screen. After the greetings the program automatically goes to the main menu.

The menus are provided by the branching function keys available in the HP-87. That is, during program execution, keys K1 to K14 can be used to interrupt the program and cause branching to a specified subroutine.

The main menu is shown in Figure 4. In this menu the keys K1,K2 and K3 are respectively assigned to the "STARTUP", "DEVICES" and "EXIT" customizing typing aids.

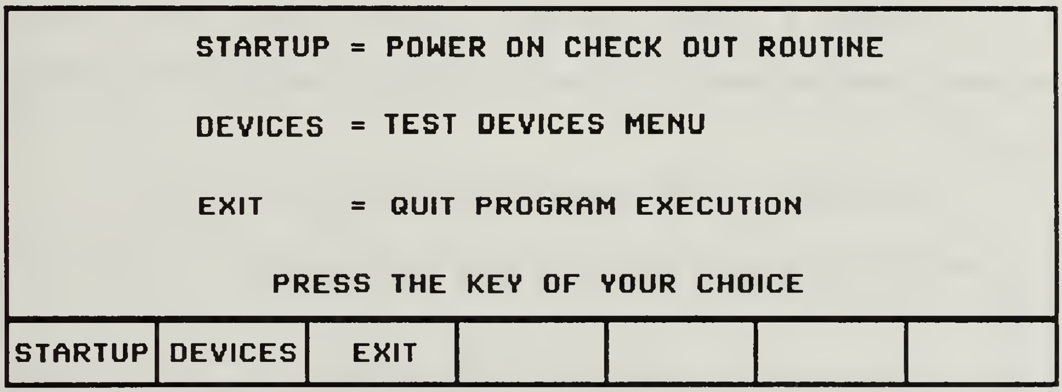

Figure 4. The main menu

From the main menu the operator can either call the power-on check-out routine, go to the test devices menu, or quit the program execution.

The power-on check-out routine menu in Figure 5 gives the operator the possibility of individually testing the

presence of each device in the system. The mass storage does not need to be checked since it is already operating from the beginning of the program.

THIS CHECKS WHICH DEVICES ARE RESPONDING

TO THE CONTROLLER COMMANDS

PRESS THE KEY OF YOUR OPTION

OF235	22XLA	2275XQ	PLOTTER	PRINTER	RETURN	

Figure 5. The power-on check-out menu

Figure 6 shows the test devices menu where the system operator has access to the functions peculiar to each test device.

OPTICAL TEST DEVICES

PRESS THE KEY OF YOUR OPTION

OF235	22XLA	2275XQ	QUIT			

Figure 6. The test devices menu

For each device in the test devices menu there are a set up routine, a data acquisition routine, and a documentation routine. These routines have essentially the same logical development for all devices and the way they are implemented is dependent upon the GPIB capabilities of each instrument. For the OF235 Reflectometer, the routines have the following set of menus:

a. <u>The OF235 general menu</u>

Pressing the key "K1" in the test devices menu causes the OF235 to go to remote mode, sets it to its default values, and gives access to the OF235 general menu shown in Figure 7.

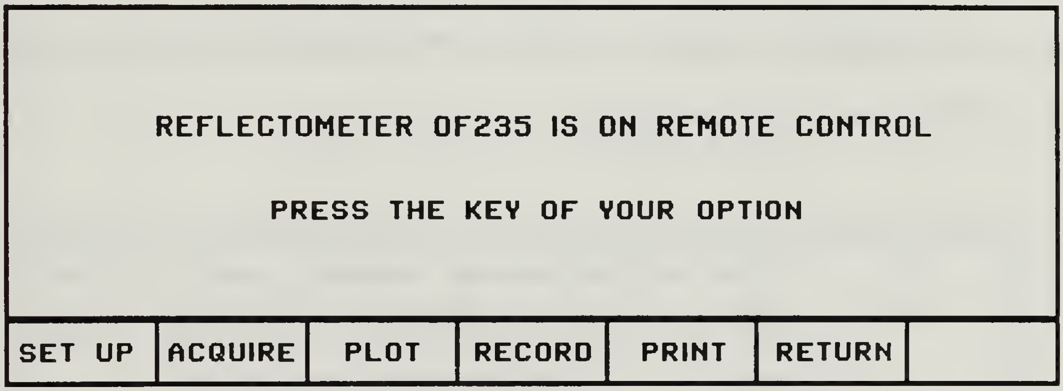

Figure 7. The OF235 general menu

b. <u>The OF235 set-up menu</u>

The set-up menu shown in Figure 8 enables the operator to change the settings of the OF235 Reflectometer. In this menu each option has the current assigned mode put on

the top of the key label and it will be updated with the new set up for that option.

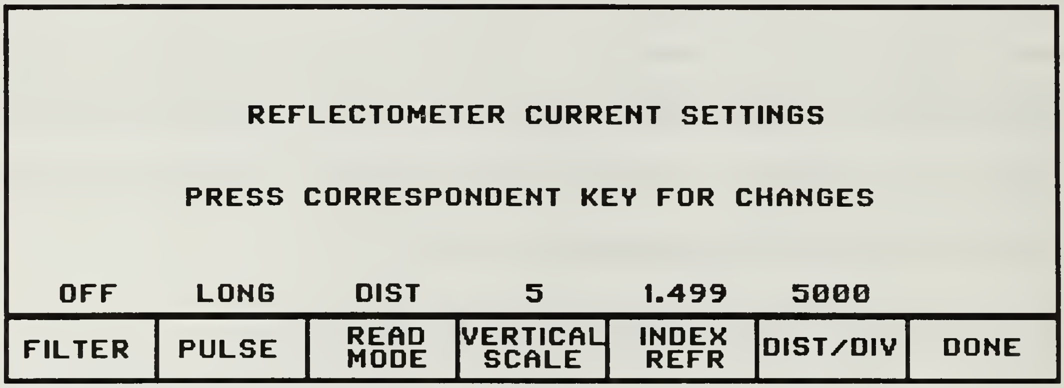

Figure 8. The OF235 set-up menu

For all options in the set-up menu other sub menus with the options for each particular case will follow. Figure 9 is an example of these other sub menus. In this sub menu the operator has the option to change the way the measurements in the OF235 will be averaged.

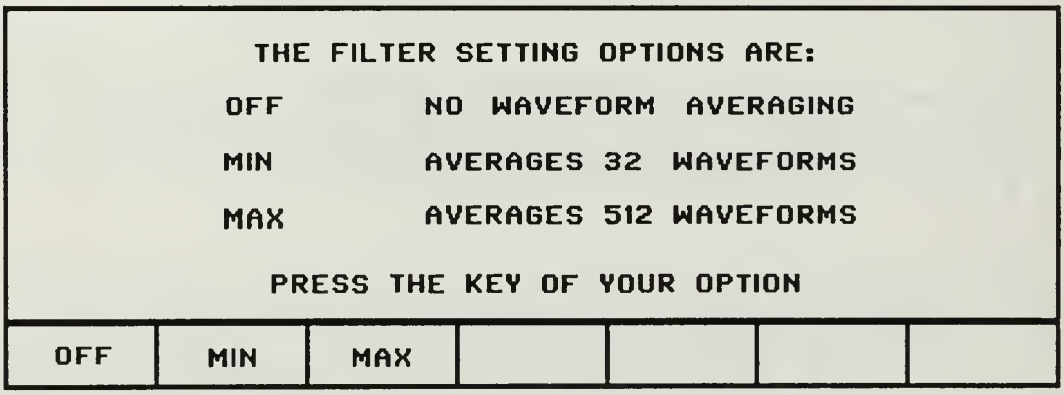

Figure 9. The OF235 filter set-up menu

c. The OF235 data acquisition menu

The data acquisition menu in Figure 10 provides some options for data acquisition with the OF235 Reflectometer. In this menu the operator can chose among the following options:

- SWEEP
- AVGS
- DIST
- DONE

Each of these options has another menu with an on-screen description of how to set it up.

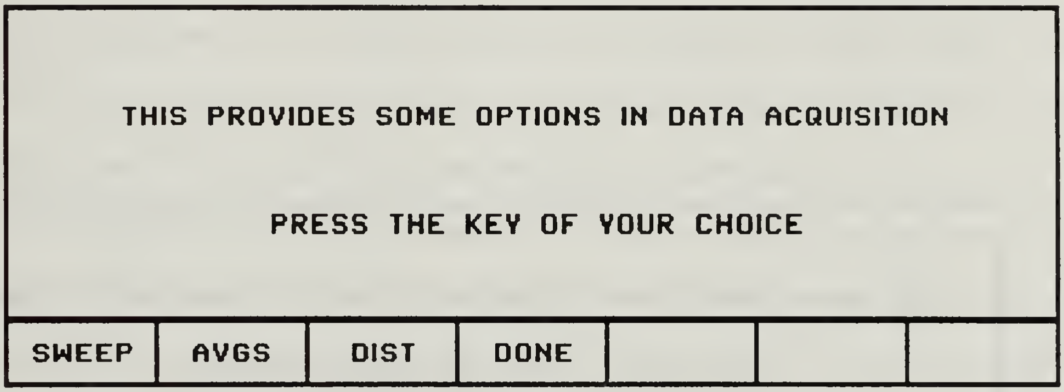

Figure 10. The OF235 data acquisition menu

d. The plot, print and record menus

The plot menu in Figure 11 reminds the operator about loading the plotter with paper and gives him the option of aborting the plotting routine. The print menu on Figure 12 reminds the operator about the state of the printer and gives

the option of halting the printing. The record menu in Figure 13 gives to the operator the option of making a copy of the current displayed waveform in the strip chart recorder of the OF235 Reflectometer.

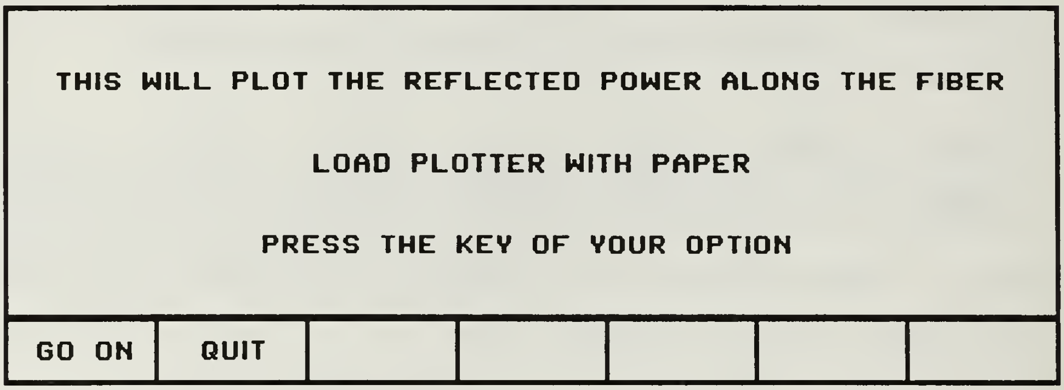

Figure 11. The plot menu

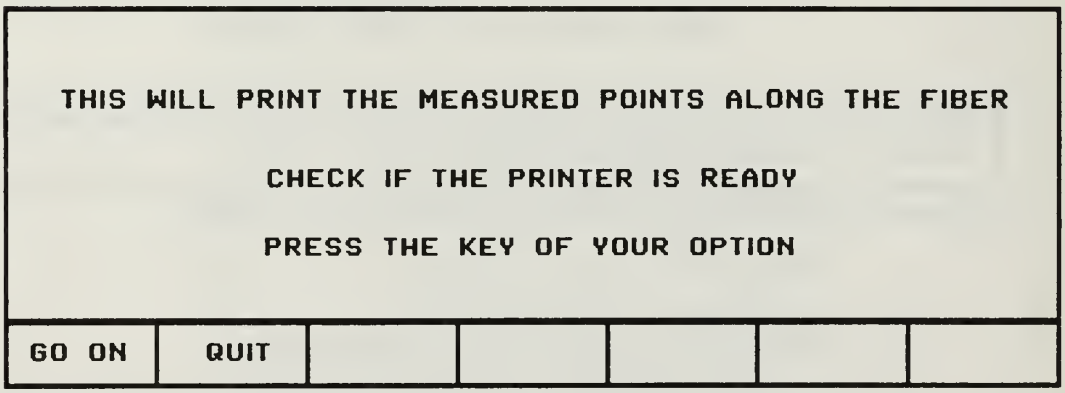

Figure 12. The print menu

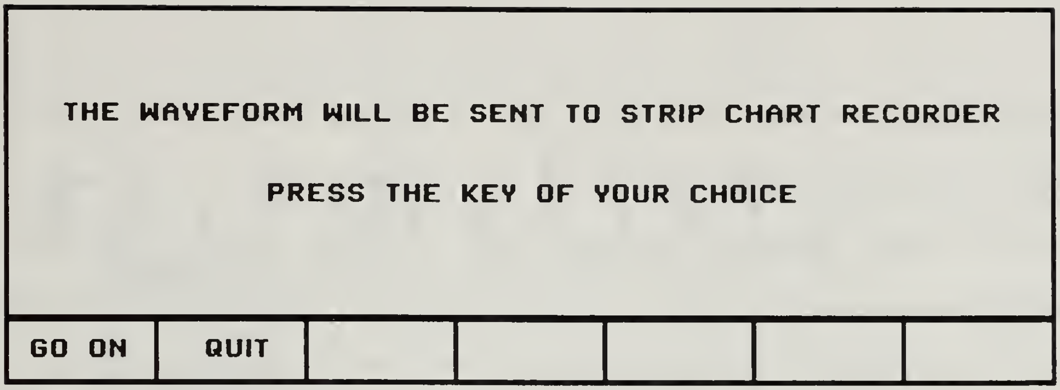

Figure 13. The record menu

C. SYSTEM OUTPUT

An automated system may generate output data in many different ways depending on the kind of experiment that is being performed. In this project the device under test is an 11 kilometer cable of single-mode optic fiber. Therefore, the system has fiber optical parameters as output.

The output for this system can be either a printed list with the measured points along the fiber or a plot of the waveform shaped by those points. Figure 14 is an example of a plotted waveform from a measurement using the OF235 Reflectometer. In this plot the horizontal axis represents the distance along the fiber and the vertical axis represents the relative reflected power. All settings and calculations that appear on the front panel of the instrument are shown on the right of the plot.

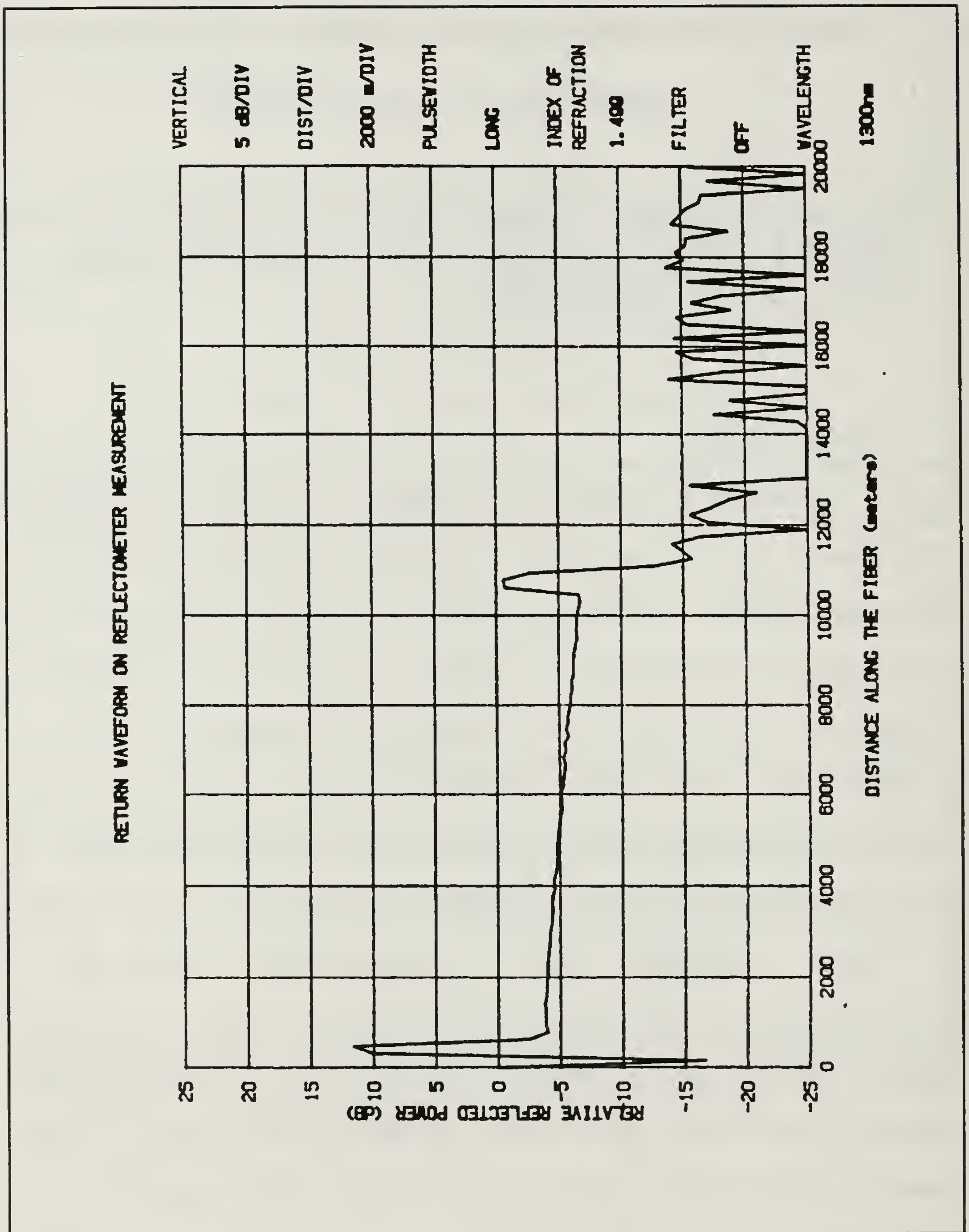

Figure 14. The output waveform on a reflectometer measurement

The waveform in this plot is a typical output of a single-mode optical time domain reflectometer (OTDR). The uppermost line is a reference point indicating the power launched into the fiber under test, allowing for reasonable coupling losses through the OTDR system. The second higher pulse in the drawing is the reflection at the end of the fiber, and between the two pulses there is the backscatter reflection. The backscatter signal that returns to the OTDR is of constant amplitude except for attenuation of the pulse traveling forward and the reflections traveling back through the fiber. Thus, the time decay of the backscatter signal provides a measurement of fiber attenuation. The pulses below the -15 dB level represent the receiver noise equivalent power which is essentially the minimum detectable signal, given the receiver's electronic noise and realistic coupling losses in the optical path into the instrument.

The printed list with the measured points in the presented waveform can be seen in the Appendix A.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The automated system implemented in this thesis has merits as well as limitations in terms of the equipment and software used to accomplish the objectives as well as the way the system was implemented.

Using the HP-87 desktop computer as the system controller reduces the test-system functionality since more advanced controllers will have multi-level operating systems with several layers of interrupt priority as regards the servicing of control lines and units on the interfaces. Some advanced computers have the ability to run a live keyboard, do computations, and operate both the display and run the program simultaneously. In contrast, a desktop computer takes on each task individually: driving the bus, reading the keyboard entry, executing the graphics. Through time sharing, the program running and processing temporarily blanks out the other functions. On the other hand, controller prices can become quite expensive before attaining the required specification level with the incorporation of enhanced facilities and it is in this context that desktop computers have their advantages. In a production application, for instance, the user can gain better control over the

manufacturing process because, using a low-cost system, he or she can test small lots of parts that would be too expensive to send to an outside test facility. In the case of this project, the use of the HP-87 was a very good choice. A plausible argument for it is that it is possible to accomplish the objectives of the project and simultaneously give use to an available desktop computer that might otherwise go unused considering the plethora of more advanced machines. Another argument for the use of available inexpensive equipment is that it is usually quite adept at controlling other expensive, sophisticated equipment, particularly in military applications such as a $20,000 optical reflectometer, not to mention that the system can be expanded and integrate more of such expensive testers.

The decision of using the HP-87 desktop computer induces the use of its built in language BASIC for programming the system. As was explained early, the use of a high-level language requires that a compiler be used to translate the written program into machine code. So called "Compiled" languages are converted before run-time and executed in that form (i.e., C and PASCAL). The entire program must be debugged as a whole. "Interpreted" languages are "incrementally compiled" (e.g., BASIC). That is, as each line of the original code is read, it is converted and executed. This permits a

single program line to be written and tested independently making BASIC a good choice for programming automated systems.

Another aspect that should be taken into account when developing a system like the one undertaken in this project is the time that must be spent by the designer to accomplish a comprehensive debugging plan for the system software. That is, a step-by-step comparison should be made with manual measurement techniques to preclude the possibility of subtle program anomalies which may lead to erroneous test results. The time available for a thesis work is not enough for the realization of a complete software validation and some unpredicted and undesirable situations may occur during the life of the system and should be guarded against.

B. RECOMMENDATIONS

It was suggested in this work that one of the limitations of an automated system using the GPIB is the total accumulated cable length of 20 meters for the interconnection of the system devices. Thus, as a future extension of the present work it might prove advantageous to explore methods to overcome this limitation.

Another consideration would be to expand the IEEE 488 bus beyond the confines of a laboratory by using a bus extender that includes an RS-232 interface and can connect to modems

to exchange data across long distances via direct-dial private telephone lines as it is shown in Figure 15.

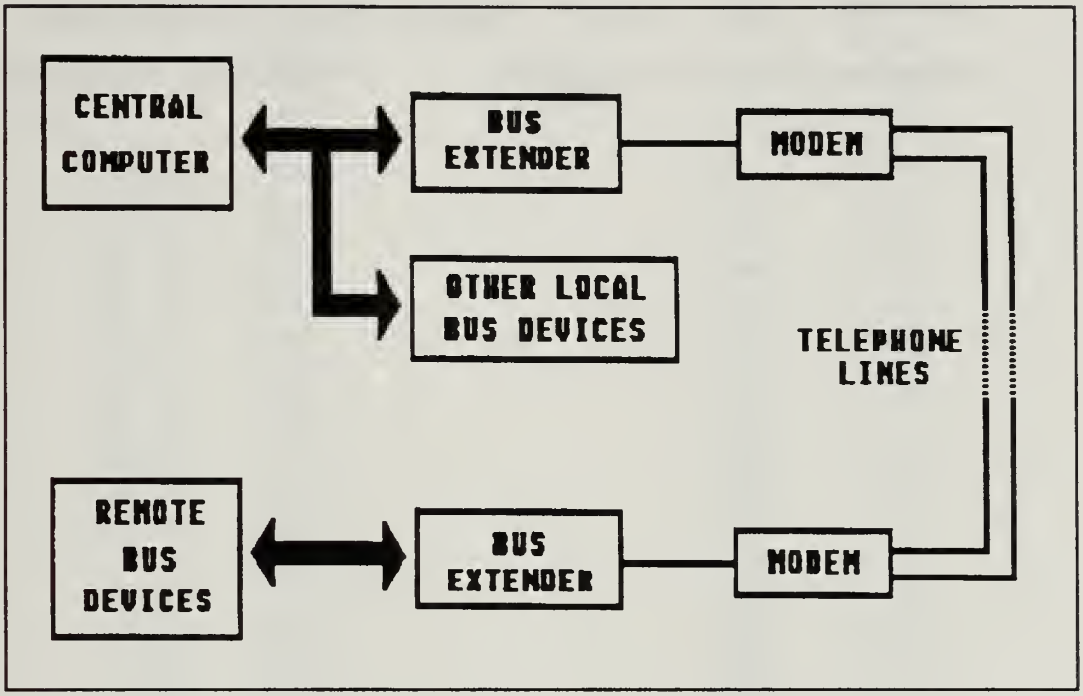

Figure 15. An extended automated system

In this manner, the test setup could be used to monitor remote locations.

APPENDIX A

OUTPUT DATA FROM THE OF235 REFLECTOMETER

OPTICAL TIME DOMAIN REFLECTOMETER MEASUREMENT

DISTANCE ALONG THE FIBER(m)	RELATIVE POWER(dB)
0	-16.62
160	10.09
320	11.59
480	-2.48
640	-3.99
800	-3.99
960	-3.86
1120	-3.88
1280	-3.78
1440	-3.88
1600	-3.89
1760	-3.89
1920	-4.00
2080	-3.99
2240	-4.01
2400	-4.07
2560	-4.12
2720	-4.21
2880	-4.21
3040	-4.32
3200	-4.35
3360	-4.43
3520	-4.37
3680	-4.43
3840	-4.61
4000	-4.52
4160	-4.65
4320	-4.74
4480	-4.83
4640	-4.80
4800	-4.84
4960	-4.85
5120	-4.94
5280	-5.01
5440	-5.09
5600	-5.21
5760	-5.18
5920	-5.11
6080	-5.32

DISTANCE ALONG THE FIBER(m)	RELATIVE POWER(dB)
6240	-5.32
6400	-5.40
6560	-5.48
6720	-5.35
6880	-5.55
7040	-5.44
7200	-5.76
7360	-5.57
7520	-5.70
7680	-5.71
7840	-5.84
8000	-5.93
8160	-5.98
8320	-6.06
8480	-6.06
8640	-6.20
8800	-6.18
8960	-6.18
9120	-6.25
9280	-6.36
9440	-6.50
9600	-6.43
9760	-6.47
9920	-6.48
10080	-6.59
10240	-6.73
10400	-6.62
10560	-0.71
10720	-0.57
10880	-2.61
11040	-12.68
11200	-15.71
11360	-15.01
11520	-14.18
11680	-16.31
11840	-25.00
12000	-17.04
12160	-15.63
12320	-17.31
12480	-18.64
12640	-20.91
12800	-15.63
12960	-25.00
13120	-25.00
13280	-25.00
13440	-25.00
13600	-25.00
13760	-25.00
13920	-25.00

DISTANCE ALONG THE FIBER(m)	RELATIVE POWER(dB)
14080	-25.00
14240	-24.30
14400	-17.60
14560	-25.00
14720	-18.91
14880	-25.00
15040	-25.00
15200	-13.96
15360	-18.03
15520	-25.00
15680	-15.90
15840	-14.60
16000	-25.00
16160	-14.45
16320	-24.96
16480	-15.39
16640	-14.67
16800	-18.93
16960	-15.85
17120	-18.10
17280	-25.00
17440	-15.55
17600	-25.00
17760	-13.80
17920	-15.16
18080	-14.62
18240	-15.34
18400	-15.43
18560	-18.75
18720	-14.28
18880	-14.83
19040	-15.37
19200	-16.47
19360	-16.64
19520	-25.00
19680	-17.25
19840	-25.00
20000	-15.61

APPENDIX B

THE SYSTEM PROGRAM

```
10 CLEAR @ OPTION BASE 1
20 ! *** SYSTEM GREETINGS ROUTINE***
30 PLOTTER IS 1
40 GCLEAR
50 FRAME
60 DEG
70 CSIZE 16,.6
80 MOVE 18,80
90 LABEL "    WELCOME  "
100 MOVE 68,65
110 CSIZE 7,.6
120 LABEL " TO  THE "
130 CSIZE 10
140 FOR KA=0 TO 3
150 MOVE KA/3+14,47
160 LABEL "AUTOMATED FIBER OPTIC"
170 MOVE KA/3+27,23
180 LABEL "MEASUREMENT SYSTEM"
190 NEXT KA
200 WAIT 2000 @ GCLEAR
210 CLEAR @ OFF KEY#
220 DISP USING 230
230 IMAGE ""5/""
240 DISP "                     PRESS THE KEY OF YOUR OPTION"
250 ON KEY# 1," BUS TEST" GOTO 300
260 ON KEY# 2," DEVICES" GOTO 970
270 ON KEY# 3,"  EXIT" GOTO 6850
280 KEY LABEL
290 GOTO 290
300 CLEAR @ OFF KEY#
310 DISP USING 320
320 IMAGE ""5/""
330 DISP "                       POWER ON CHECK OUT ROUTINE"
340 DISP @ DISP
350 DISP
360 DISP
370 DISP "                     PRESS THE KEY OF YOUR OPTION"
380 ON KEY# 1,"  OF-235" GOTO 460
390 ON KEY# 2,"  2275XQ" GOTO 560
400 ON KEY# 3,"  22XLA" GOTO 660
410 ON KEY# 4," PLOTTER" GOTO 760
420 ON KEY# 5," PRINTER" GOTO 860
430 ON KEY# 6," RETURN" GOTO 210
440 KEY LABEL
450 GOTO 450
```

```
460 CLEAR @ OFF KEY#
470 DISP USING 480
480 IMAGE ""5/""
490 DISP "                    THE OF-235 DOES NOT RESPOND" @ DISP
500 DISP "                     THE BUS HUNG UP.   PRESS 'RESET'"
510 A5=SPOLL (704) @ CLEAR
520 DISP USING 530
530 IMAGE ""5/""
540 DISP "                             OF-235 IS UNDER CONTROL"
550 WAIT 1500 @ GOTO 300
560 CLEAR @ OFF KEY#
570 DISP USING 580
580 IMAGE ""5/""
590 DISP "                    THE 2257XQ DOES NOT RESPOND" @ DISP
600 DISP "                     THE BUS HUNG UP.   PRESS 'RESET'"
610 A6=SPOLL (706) @ CLEAR
620 DISP USING 630
630 IMAGE ""5/""
640 DISP "                             2275XQ IS UNDER CONTROL"
650 WAIT 1500 @ GOTO 300
660 CLEAR @ OFF KEY#
670 DISP USING 680
680 IMAGE ""5/""
690 DISP "                     THE 22XLA DOES NOT RESPOND" @ DISP
700 DISP "                     THE BUS HUNG UP.  PRESS 'RESET'"
710 ENTER 702 ; A8@ CLEAR
720 DISP USING 730
730 IMAGE ""5/""
740 DISP "                             22XLA IS UNDER CONTROL"
750 WAIT 1500 @ GOTO 300
760 CLEAR @ OFF KEY#
770 DISP USING 780
780 IMAGE ""5/""
790 DISP "                   THE PLOTTER DOES NOT RESPOND" @ DISP
800 DISP "                   THE BUS HUNG UP.  PRESS 'RESET'"
810 PRINTER IS 705 @ PRINT "OI;" @ ENTER 705 ; B1$ @ PRINTER
    IS 1 @ CLEAR
820 DISP USING 830
830 IMAGE ""5/""
840 DISP "                           PLOTTER IS UNDER CONTROL"
850 WAIT 1500 @ GOTO 300
860 CLEAR @ OFF KEY#
870 DISP USING 880
880 IMAGE ""3/""
890 PRINTER IS 701 @ PRINT "PRINTER IS UNDER CONTROL" @
    PRINTER IS 1
900 DISP "           THE PRINTER CAN NOT RESPOND" @ DISP
910 DISP "          SINCE  IT'S JUST A LISTENER DEVICE" @ DISP
920 DISP "           VERIFY IF IT HAS PRINTED:" @ DISP
930 DISP "           'PRINTER IS UNDER CONTROL'" @ DISP
940 DISP "           PRESS 'CONT' WHEN DONE"
```

```
950 PAUSE
960 GOTO 300
970 DISP USING 980
980 IMAGE """5/"""
990 DISP "           THESE ARE THE TEST DEVICES" @ DISP @ DISP
1000 DISP"          PRESS THE KEY OF YOUR OPTION"
1010 ON KEY# 1,"  OF235" GOTO 1070
1020 ON KEY# 2,"  22XLA" GOTO 4890
1030 ON KEY# 3,"  2275XQ" GOTO 6890
1040 ON KEY# 4,"  QUIT" GOTO 210
1050 KEY LABEL
1060 GOTO 1060
1070 CLEAR @ OFF KEY#
1080 FILTER$="     OFF"
1090 PULSE$="      LONG"
1100 MODE$="     DIST"
1110 VERT=5
1120 IRF=1.499
1130 SHORT P(1024)
1140 DIS=5000
1150 SHORT PO(126)
1160 SHORT ZA(126)
1170 OUTPUT 704 ;"INIT" @ S=SPOLL (704)
1180 CLEAR @ OFF KEY#
1190 DISP USING 1200
1200 IMAGE """4/"""
1210 DISP "         REFLECTOMETER 0F235 IS ON REMOTE CONTROL"
1220 DISP @ DISP "       PRESS THE KEY OF YOUR OPTION"
1230 ON KEY# 1,"  SET UP" GOTO 1310
1240 ON KEY# 2," ACQUIRE" GOTO 2710
1250 ON KEY#3,"    PLOT" GOTO 3420
1260 ON KEY# 4,"  RECORD" GOTO 3310
1270 ON KEY# 5,"  PRINT" GOTO 4450
1280 ON KEY# 6," RETURN" GOTO 210
1290 KEY LABEL
1300 GOTO 1300
1310 CLEAR @ OFF KEY#
1320 ON KEY# 1,"  FILTER" GOTO 1490
1330 ON KEY# 2,"  PULSE" GOTO 1690
1340 ON KEY# 3,"READ MODE" GOTO 1890
1350 ON KEY# 4,"VERT SCALE" GOTO 2120
1360 ON KEY# 5,"INDEX REFR" GOTO 2300
1370 ON KEY# 6,"DIST/DIV" GOTO 2410
1380 ON KEY# 7,"  DONE" GOTO 1180
1390 KEY LABEL
1400 DISP USING 1410
1410 IMAGE """5/"""
1420 DISP "              REFLECTOMETER CURRENT SETTINGS"
1430 DISP
1440 DISP "           PRESS CORRESPONDENT KEY FOR CHANGES"
1450 DISP USING 1410
```

```
1460 DISP USING 1470 ; FILTER$,PULSE$,MODE$,VERT,IRF,DIS
1470 IMAGE X,8A,X,11A,X,9A,7X,D.2D,6X,D.3D,6X,4D
1480 GOTO 1480
1490 CLEAR @ OFF KEY#
1500 ON KEY# 1,"  OFF  "GOTO 1640
1510 ON KEY# 2,"  MIN  "GOTO 1650
1520 ON KEY# 3,"  MAX  "GOTO 1660
1530 KEY LABEL
1540 DISP USING 1550
1550 IMAGE ""4/""
1560 DISP "  THE FILTER SETTING OPTIONS ARE:"
1570 DISP
1580 DISP "  OFF              NO WAVEFORM AVERAGING"
1590 DISP "  MIN              AVERAGES 32 WAVEFORMS"
1600 DISP "  MAX              AVERAGES 512 WAVEFORMS"
1610 DISP
1620 DISP "  PRESS THE KEY OF YOUR CHOICE"
1630 GOTO 1630
1640 FILTER$="    OFF" @ OUTPUT 704 ;"FILTER OFF" @ GOTO 1670
1650 FILTER$="    MIN" @ OUTPUT 704 ;"FILTER MIN" @ GOTO 1670
1660 FILTER$="    MAX" @ OUTPUT 704 ;"FILTER MAX" @ GOTO 1670
1670 OUTPUT 704 ;"FILTER?" @ ENTER 704 ; FILTER$ @
     FILTER$[1,4]=""
1680 GOTO 1310
1690 CLEAR @ OFF KEY#
1700 ON KEY# 1,"  SHORT" GOTO 1840
1710 ON KEY# 2,"   MED " GOTO 1850
1720 ON KEY# 3,"   LONG " GOTO 1860
1730 KEY LABEL
1740 DISP USING 1750
1750 IMAGE ""4/""
1760 DISP "  THE PULSE SETTING OPTIONS ARE:"
1770 DISP
1780 DISP "  SHORT          SETS OPTICAL PULSE WIDTH TO 0.5 s"
1790 DISP "  MEDIUM         SETS OPTICAL PULSE WIDTH TO 1.5 s"
1800 DISP "  LONG           SETS OPTICAL PULSE WIDTH TO 4.0 s"
1810 DISP
1820 DISP "  PRESS THE KEY OF YOUR CHOICE"
1830 GOTO 1830
1840 PULSE$="    SHORT" @ OUTPUT 704 ;"PULSE SHORT" @ GOTO
1870
1850 PULSE$="    MED" @ OUTPUT 704 ;"PULSE MED" @ GOTO 1870
1860 PULSE$="   LONG" @ OUTPUT 704 ;"PULSE LONG" @ GOTO 1870
1870 OUTPUT 704 ;"PULSE?" @ ENTER 704 ; PULSE$@ PULSE$[1,5]=""
1880 GOTO 1310
1890 CLEAR @ OFF KEY#
1900 ON KEY# 1,"   DIST" GOTO 2060
1910 ON KEY# 2,"   MAN" GOTO 2070
1920 ON KEY# 3,"   AUTO" GOTO 2080
1930 ON KEY# 4,"   SLOP" GOTO 2090
1940 KEY LABEL
```

```
1950 DISP USING 1960
1960 IMAGE ""4/""
1970 DISP "  THE MODE SETTING OPTIONS ARE:"
1980 DISP
1990 DISP "  DIST    SETS MODE TO DISTANCE"
2000 DISP "  MAN     SETS LOSS MEASUREMENTS TO MANUAL MODE"
2010 DISP "  AUTO    SETS LOSS MEASUREMENTS TO AUTOMATIC MODE"
2020 DISP "  SLOP    SETS LOSS MEASUREMENTS TO /Km MODE"
2030 DISP
2040 DISP "  PRESS THE KEY OF YOUR CHOICE"
2050 GOTO 2050
2060 MODE$="    DIST" @ OUTPUT 704 ;"MODE DIST" @ GOTO 2100
2070 MODE$="    MAN" 2 OUTPUT 704 ;"MODE MANUAL" @ GOTO 2100
2080 MODE$="    AUTO:\" @ OUTPUT 704 ;"MODE AUTO" @ GOTO 2100
2090 MODE$="    SLOP" @ OUTPUT 704 ;"MODE SLOP" @ GOTO 2100
2100 OUTPUT 704 ;"MODE?" @ ENTER 704 ; MODE$@ MODE$[1,4]=""
2110 GOTO 1310
2120 CLEAR @ OFF KEY#
2130 ON KEY# 1,"   .25" GOTO 2250
2140 ON KEY# 2,"    1" GOTO 2260
2150 ON KEY# 3,"    5" GOTO 2270
2160 KEY LABEL
2170 DISP USING 2180
2180 IMAGE ""4/""
2190 DISP "  VERTICAL SCALE SETTING (dB/DIV)"
2200 DISP
2210 DISP
2220 DISP "  PRESS THE KEY OF YOUR CHOICE"
2230 GOTO 2230
2240 DISP
2250 VERT=.25 @ OUTPUT 704 ;"VERTICAL .25" @ GOTO 2280
2260 VERT=1 @ OUTPUT 704 ;"VERTICAL 1" @ GOTO 2280
2270 VERT=5 @ OUTPUT 704 ;"VERTICAL 5" @ GOTO 2280
2280 OUTPUT 704 ;"VERTICAL?" @ ENTER 704 ; VERT
2290 GOTO 1310
2300 CLEAR
2310 DISP USING 2320
2320 IMAGE ""4/""
2330 DISP "  CHOOSE THE REQUIRED INDEX OF REFRACTION."
2340 DISP
2350 DISP "  ENTER ANY DECIMAL NUMBER BETWEEN 1.400 AND 1.599"
2360 INPUT I1
2370 IF I1<1.4 OR I1>1.599 THEN 2350
2380 OUTPUT 704 ;"IR";I1
2390 OUTPUT 704 ;"IR?" @ ENTER 704 ; IRF
2400 CLEAR @ GOTO 1310
2410 CLEAR @ OFF KEY#
2420 ON KEY# 1,"    5" GOTO 2590
2430 ON KEY# 2,"   10" GOTO 2600
2440 ON KEY# 3,"   20" GOTO 2610
2450 ON KEY# 4,"   50" GOTO 2620
```

```
2460 ON KEY# 5,"   100" GOTO 2630
2470 ON KEY# 6,"   200" GOTO 2640
2480 ON KEY# 7,"   500" GOTO 2650
2490 ON KEY# 12,"   1000" GOTO 2660
2500 ON KEY# 13,"   2000" GOTO 2670
2510 ON KEY# 14,"   5000" GOTO 2680
2520 KEY LABEL
2530 DISP USING 2540
2540 IMAGE ""4/""
2550 DISP "  DISTANCE PER DIVISION SETTING (m/DIV)"
2560 DISP
2570 DISP "  PRESS THE KEY OF YOUR CHOICE"
2580 GOTO 2580
2590 DIS=5 @ OUTPUT 704 ;"DXDIV 5" @ GOTO 2690
2600 DIS=10 @ OUTPUT 704 ;"DXDIV 10" @ GOTO 2690
2610 DIS=20 @ OUTPUT 704 ;"DXDIV 20" @ GOTO 2690
2620 DIS=50 @ OUTPUT 704 ;"DXDIV 50" @ GOTO 2690
2630 DIS=100 @ OUTPUT 704 ;"DXDIV 100" @ GOTO 2690
2640 DIS=200 @ OUTPUT 704 ;"DXDIV 200" @ GOTO 2690
2650 DIS=500 @ OUTPUT 704 ;"DXDIV 500" @ GOTO 2690
2660 DIS=1000 @ OUTPUT 704 ;"DXDIV 1000" @ GOTO 2690
2670 DIS=2000 @ OUTPUT 704 ;"DXDIV 2000" @ GOTO 2690
2680 DIS=5000 @ OUTPUT 704 ;"DXDIV 5000" @ GOTO 2690
2690 OUTPUT 704 ;"DXDIV?" @ ENTER 704 ; DIS
2700 GOTO 1310
2710 CLEAR @ OFF KEY#
2720 DISP USING 2730
2730 IMAGE ""5/""
2740 DISP " THIS PROVIDES SOME OPTIONS IN DATA ACQUISITION"
2750 DISP
2760 DISP "                   PRESS THE KEY OF YOUR CHOICE"
2770 ON KEY# 1,"  SWEEP" GOTO 2990
2780 ON KEY# 2,"   AVGS" GOTO 3200
2790 ON KEY# 3,"   DIST" GOTO 2830
2800 ON KEY# 4,"  DONE" GOTO 1180
2810 KEY LABEL
2820 GOTO 2820
2830 CLEAR @ OFF KEY#
2840 OUTPUT 704 ;"DIST?" @ ENTER 704 ; D1@ DISP @ DISP
2850 DISP "           PRESENT 1ST DATA POINT:";D1;"m"
2860 DISP USING 2870
2870 IMAGE ""2/""
2880 DISP "    ENTER   THE   POINT  ALONG   THE   FIBER   YOU"
2890 DISP
2900 DISP "    WANT DATA ACQUISITON TO BEGIN (USE METERS)"
2910 DISP
2920 DISP "    RANGE:   INTEGER   FROM  -25    TO    107432"
2930 DISP
2940 DISP " MAXIMUM NUMBER IS DEPENDENT UPON THE IR SETTING"
2950 INPUT D1
2960 IF D1>= -25 AND D1<= 107432 THEN 2970 ELSE 2830
```

```
2970 OUTPUT 704 ;"DIST",D1
2980 GOTO 2710
2990 CLEAR @ OFF KEY#
3000 DISP USING 3010
3010 IMAGE ""3/""
3020 DISP "     THIS CAUSES THE OF235 TO START A LASER SWEEP"
3030 DISP @ DISP "  AND ACQUIRE DATA IN ITS LOCAL MEMORY"
3040 DISP
3050 DISP "     CONTIN       CAUSES REPEATED SWEEPS TO OCCUR"
3060 DISP
3070 DISP "     SINGLE       CAUSES  A SINGLE SWEEP TO OCCUR"
3080 DISP
3090 DISP "  STOP     USE TO STOP THE CHOSEN SWEEP AND RETURN"
3100 ON KEY# 1,"  CONTIN" GOTO 3150
3110 ON KEY# 2,"  SINGLE" GOTO 3160
3120 ON KEY# 3,"  STOP" GOTO 3170
3130 KEY LABEL
3140 GOTO 3140
3150 OUTPUT 704 ;"SW C" @ GOTO 2990
3160 OUTPUT 704 ;"SW S" @ GOTO 2990
3170 OUTPUT 704 ;"ST" @ GOTO 2710
3180 KEY LABEL
3190 GOTO 3190
3200 CLEAR @ OFF KEY#
3210 DISP USING 3220
3220 IMAGE ""5/""
3230 DISP "         THIS IS THE NUMBER OF WAVEFORMS" @ DISP
3240 DISP "         AVERAGED IN THE CURRENT CURVE DATA"
3250 ON KEY# 1," RETURN" GOTO 2710
3260 OUTPUT 704 ;"AV?" @ ENTER 704 ; k
3270 DISP
3280 DISP "                                        ";K
3290 KEY LABEL
3300 GOTO 3300
3310 CLEAR @ OFF KEY#
3320 DISP USING 3330
3330 IMAGE ""5/""
3340 DISP "THE WAVEFORM WILL BE SENT TO THE STRIP CHART
     RECORDER"
3350 DISP
3360 DISP "                    PRESS THE KEY OF YOUR OPTION"
3370 ON KEY# 1,"  GO ON" GOTO 3410
3380 ON KEY# 2,"  QUIT" GOTO 1180
3390 KEY LABEL
3400 GOTO 3400
3410 OUTPUT 704 ;"RECORD" @ GOTO 1180
3420 CLEAR
3430 DISP USING 3440
3440 IMAGE ""4/""
3450 DISP "   THIS WILL PLOT THE REFLECTED POWER ALONG THE
     FIBER "
```

```
3460 DISP
3470 DISP "                              LOAD PLOTTER WITH PAPER "
3480 DISP
3490 DISP "                          PRESS THE KEY OF YOUR OPTION"
3500 OFF KEY#
3510 ON KEY# 1,"  GO ON" GOTO 3550
3520 ON KEY# 2,"   QUIT" GOTO 1180
3530 KEY LABEL
3540 GOTO 3540
3550 U=1
3560 CLEAR @ DISP USING 3570
3570 IMAGE ""2/""
3580 DISP "          LOADING DATA PLEASE WAIT" @ DISP @ DISP
3590 TI=TIME
3600 RANDOMIZE TI
3610 R=RND
3620 IF R<= .1 THEN GOTO 3630 ELSE 3660
3630 DISP "INTUITION" @ DISP
3640 DISP "INTUITION IS WHAT ENABLES A WIFE TO CONTRADICT"
     @ DISP
3650 DISP "HER   HUSBAND   BEFORE   HE   SAYS   ANYTHING."
3660 IF R>.1 AND R<= .2 THEN GOTO 3670 ELSE 3700
3670 DISP "LIFE/LOVE" @ DISP
3680 DISP "LIFE  IS  JUST  ONE  DUMB THING AFTER ANOTHER,"
3690 DISP "LOVE IS JUST TWO DUMB THINGS AFTER EACH OTHER."
3700 IF R>.2 AND R<= .3 THEN GOTO 3710 ELSE 3750
3710 DISP "HUSBANDS" @ DISP
3720 DISP "HUSBANDS ARE THOSE WHO BELONG TO THE" @ DISP
3730 DISP "'HONEY  DEW  ASSOCIATION.'   IT IS, " @ DISP
3740 DISP "'HONEY, , DO THIS' AND 'HONEY DO THAT.'"
3750 IF R>.3 AND R<= .4 THEN GOTO 3760 ELSE 3790
3760 DISP "OLD AGE" @ DISP
3770 DISP "OLD AGE IS THE TIME WHEN MEN PAY MORE ATTENTION"
     @ DISP
3780 DISP "TO  THEIR  FOOD  THAN  THEY DO TO THE WAITRESS."
3790 IF R>.4 AND R<= .5 THEN GOTO 3800 ELSE 3840
3800 DISP "COMMITTEE" @ DISP
3810 DISP "A COMMITTEE IS A GROUP OF PEOPLE WHO INDIVIDUALLY"
     @ DISP
3820 DISP "CAN DO NOTHING, BUT  WHO AS A GROUP CAN MEET AND"
     @ DISP
3830 DISP "DECIDE THAT NOTHING CAN BE DONE."
3840 IF R>.5 AND R<= .6 THEN GOTO 3850 ELSE 3890
3850 DISP "BRAIN" @ DISP
3860 DISP "THE BRAIN IS THE ONLY PART OF THE HUMAN MACHINE"
     @ DISP
3870 DISP "THAT DOESN'T WEAR OUT. PROBABLY IT'S BECAUSE THE"
     @ DISP
3880 DISP "BRAIN IS THE ONLY PART THAT IS NEVER OVERWORKED."
3890 IF R>.6 AND R<= .7 THEN GOTO 3900 ELSE 3930
3900 DISP "BANKER" @ DISP
```

```
3910 DISP "A BANKER IS A MAN WHO WILL LOAN YOU MONEY IF"
     @ DISP
3920 DISP "YOU  CAN  PROVE  TO  HIM YOU DON'T NEED ANY."
3930 IF R>.7 AND R<= .8 THEN GOTO 3940 ELSE 3980
3940 DISP "EXPERT" @ DISP
3950 DISP "AN EXPERT IS ONE WHO IS SMART ENOUGH TO TELL"
     @ DISP
3960 DISP "YOU HOW TO RUN YOUR BUSINESS,  BUT UNABLE TO"
     @ DISP
3970 DISP "START ONE OF HIS OWN."
3980 IF R>.8 AND R<= .9 THEN GOTO 3990 ELSE 4020
3990 DISP "HEREDITY" @ DISP
4000 DISP "HEREDITY IS WHAT A MAN BELIEVES IN UNTIL" @ DISP
4010 DISP "HIS SON BEGINS TO ACT LIKE A DELINQUENT."
4020 IF R>.9 THEN GOTO 4030 ELSE 4060
4030 DISP "HONEYMOON" @ DISP
4040 DISP "HONEYMOON IS THAT DELIGHTFUL INTERVAL" @ DISP
4050 DISP "BETWEEN BELLS AND BILLS."
4060 GOSUB 4730
4070 IF U=0 THEN 4580
4080 PLOTTER IS 705
4090 ASSIGN# 1 TO  "CURVE:D700"
4100 CLEAR @ DISP USING 4110
4110 IMAGE ""6/""
4120 DISP "                                        PLOTTING"
4130 PEN 2
4140 LOCATE 9,122,10,89
4150 OUTPUT 704 ;"DIST?" @ ENTER 704 ; DI
4160 SCALE DI,DI+10*DIS,-(5*VERT),5*VERT
4170 IF VERT=.25 THEN FXD 0,2 ELSE FXD 0,0
4180 LGRID -DIS,VERT,DI,0,1,1
4190 MOVE 10.2*DIS+DI,5*VERT @ LABEL "VERTICAL"
4200 MOVE 10.2*DIS+DI,3*VERT @ LABEL "DIST/DIV"
4210 MOVE 10.2*DIS+DI,VERT @ LABEL "PULSEWIDTH"
4220 MOVE 10.2*DIS+DI,-VERT @ LABEL "INDEX OF "
4230 MOVE 10.2*DIS+DI,-(1.4*VERT) @ LABEL "REFRACTION"
4240 MOVE 10.2*DIS+DI,-(3*VERT) @ LABEL "FILTER"
4250 MOVE 10.2*DIS+DI,-(5*VERT) @ LABEL "WAVELENGTH"
4260 PEN 1
4270 MOVE DI+2.5*DIS,6*VERT @ LABEL "RETURN WAVEFORM ON
     REFLECTOMETER MEASUREMENT"
4280 MOVE 10.1DIS+DI,4*VERT @ LABEL VERT;"dB/DIV"
4290 MOVE 10.1*DIS+DI,2*VERT @ LABEL DIS;"M/DIV"
4300 MOVE 9.5*DIS+DI,0 @ LABEL PULSE$
4310 MOVE 10.1*DIS+DI,-(2*VERT) @ LABEL IRF
4320 MOVE 9.7*DIS+DI,-(4*VERT) @ LABEL FILTER$
4330 MOVE 10*DIS+DI,-(6*VERT) @ LABEL "   1300nm"
4340 MOVE 3*DIS+DI,-(6*VERT) @ LABEL "DISTANCE ALONG THE
     FIBER (meters)"
4350 DEG @ LDIR 90
4360 MOVE -(.5*DIS)+DI,-(2.3*VERT) @ LABEL "RELATIVE REFLECTED
```

```
     POWER (dB)"
4370 MOVE DI,0
4380 FOR R=1 TO 126
4390 READ# 1 ; PO(R),ZA(R)
4400 PO(R)=25-PO(R)
4410 DRAW DI+DIS*R*10/126,PO(R)
4420 NEXT R
4430 ASSIGN# 1 TO  *
4440 GOTO 1180
4450 CLEAR @ OFF KEY#
4460 DISP USING 4470
4470 IMAGE ""5/""
4480 DISP "    THIS WILL PRINT THE MEASURED POINTS ALONG
     THE FIBER"
4490 DISP
4500 DISP "                         CHECK IF THE PRINTER IS READY"
4510 DISP
4520 DISP "                         PRESS  THE KEY OF YOUR OPTION"
4530 ON KEY# 1,"  GO ON" GOTO 4570
4540 ON KEY# 2,"  QUIT" GOTO 1150
4550 KEY LABEL
4560 GOTO 4560
4570 U=0 @ GOTO 3560
4580 PRINTER IS 701
4590 CLEAR @ DISP USING 4600
4600 IMAGE ""6/""
4610 DISP "                                          PRINTING"
4620 PRINT "OPTICAL TIME DOMAIN REFLECTOMETER MEASUREMENT"
4630 PRINT
4640 PRINT "DISTANCE ALONG THE FIBER(m)";"  ";"RELATIVE
     POWER (dB)"
4650 ASSIGN# 1 TO  "CURVE:D700"
4660 FOR F=1 TO 126
4670 READ# 1 ; PO(F),ZA(F)
4680 PO(F)=25-PO(F)
4690 PRINT USING 4700 ; ZA(F),PO(F)
4700 IMAGE 8X,6D,30X,3D.2D
4710 NEXT F
4720 ASSIGN# 1 TO  * @ PRINTER IS 1 @ GOTO 1180
4730 ASSIGN# 1 TO  "CURVE:D700"
4740 SHORT B1(1000)
4750 SHORT C1(1000)
4760 SHORT BP(1000)
4770 DIM X1$[1000],X2$[1000],X3$[1000]
4780 OUTPUT 704 ;"CURVE?"
4790 ENTER 704 ; X1$
4800 OUTPUT 704 ;"WFMPRE" @ ENTER 704 ; X3$
4810 BP=VAL (X3$[24] @ CP=VAL (X3$[36] @ DP=BP-CP @ S=1
4820 FOR N=7 TO LEN (X1$) STEP 6
4830 B1(N-6=VAL (X1$[N])
4840 C1(N-6)=DP+S*CP @ S=S+1
```

```
4850 PRINT# 1 ; B1(N-6),C1(N-6)
4860 NEXT N
4870 ASSIGN# 1 TO  *
4880 RETURN
4890 CLEAR @ OFF KEY#
4900 DISP USING 4910
4910 IMAGE ""5/""
4920 DISP "      THIS WILL TAKE MEASUREMENTS WITH THE 22XLA
     OPTIC POWER METER"
4930 DISP @ DISP
4940 DISP "                          PRESS THE KEY OF YOUR OPTION"
4950 ON KEY# 1,"  SET UP" GOTO 5000
4960 ON KEY# 2,"  GO ON" GOTO 5060
4970 ON KEY# 3,"  QUIT " GOTO 970
4980 KEY LABEL
4990 GOTO 4990
5000 CLEAR @ OFF KEY# @ DISP USING 5010
5010 IMAGE ""4/""
5020 DISP " THIS DEVICE IS NOT ABLE TO BE REMOTELY SET UP"
     @ DISP
5030 DISP "              YOU MAY SET IT UP ON ITS PANEL" @ DISP
5040 DISP "                   PRESS 'CONT' WHEN DONE"
5050 PAUSE
5060 CLEAR @ OFF KEY# @ DISP @ DISP @ DISP @ DISP
5070 DISP "   DO YOU WANT OUTPUT TO CRT (C) OR PRINTER(P)?"
5080 INPUT ORA$
5090 IF ORA$="C" THEN CRT IS 1 @ GOTO 5120
5100 PRINTER IS 701
5110 IF ORA$="P" THEN PRINT ALL @ GOTO 5120 ELSE 5070
5120 REM  "THIS PROGRAM ASSUMES YOU HAVE A DATA FILE"
5130 REM  "NAMED 22XLA IN THE DRIVE0 OF THE HP82901M"
5140 REM  "              DISC DRIVE                 "
5150 CLEAR
5160 DISP @ DISP "ENTER HERE THE 22XLA SET UP"
5170 ! CREATE "22XLA:D700",1024,8 ! YOU MAY USE IT TO CREATE
     THE DATA FILE
5180 ASSIGN# 1 TO  "22XLA:D700" ! OPEN DATA FILE
5190 DISP @ DISP @ DISP
5200 SHORT PA(1024)
5210 DISP "ENTER SELECT RESPONSE:(AC/DC)"
5220 INPUT RESP$
5230 IF RESP$="AC" THEN 5260
5240 IF RESP$="DC" THEN 5260
5250 GOTO 5210
5260 CLEAR @ DISP @ DISP @ DISP "ENTER SELECT MODE:(S/SH/D)"
5270 INPUT MO$
5280 IF MO$="S" THEN 5320
5290 IF MO$="SH" THEN 5390
5300 IF MO$="D" THEN 5390
5310 GOTO 5260
5320 CLEAR @ DISP @ DISP @ DISP @ DISP
```

```
5330 IF MO$="S" THEN DISP "ENTER SELECT
     REFERENCE:(MILI/MICRO)" ELSE GOTO 5380
5340 INPUT REFER$
5350 IF REFER$="MILI" THEN 5390
5360 IF REFER$="MICRO" THEN 5390
5370 GOTO 5330
5380 REFER$="NOT APPLICABLE" @ CLEAR @ DISP @ DISP @ DISP
5390 DISP "ENTER RESOLUTION: (0.1/0.01)"
5400 INPUT RESOL
5410 IF RESOL=.1 THEN 5440
5420 IF RESOL=.01 THEN 5440
5430 GOTO 5390
5440 CLEAR @ DISP @ DISP
5450 DISP "THE SET UP IS:
5460 DISP " "
5470 DISP "1) SELECT RESPONSE: ";RESP$
5480 DISP "2) SELECT MODE: ";MO$
5490 IF MO$="S" THEN DISP "3) SELECT REFERENCE: ";REFER$
5500 IF MO$ <> "S" THEN DISP "3) SELECT REFERENCE:
     NOT APPLICABLE"
5510 DISP "4) RESOLUTION: ";RESOL
5520 DISP ""
5530 DISP "DO YOU WANT TO CHANGE THESE VALUES? (Y/N)"
5540 INPUT CHANGE$
5550 IF CHANGE$="Y" THEN 5210
5560 IF CHANGE$ <> "N" THEN 5530
5570 DISP "ENTER NUMBER OF SAMPLES YOU WANT (max 1024)"
5580 INPUT SAMP
5590 IF SAMP>1024 THEN 5570
5600 IF SAMP<1 THEN 5570
5610 DISP "ENTER SAMPLE INTERVAL IN SECONDS (min 0.2)"
5620 INPUT INTER
5630 IF INTER<.2 THEN 5610
5640 TIM=INTER
5650 INTER=INTER*1000
5660 REM "DEFINE TERMINATION SEQ = CR-LF + EOI"
5670 CONTROL 7,16 ; 130,13,10 ! WRITE TO HPIB CONTROL
     REGISTERS"
5680 IF RESP$="AC" THEN DISP "AC MEASUREMENTS" @ GOTO 5710
5690 DISP "DC MEASUREMENTS"
5700 DISP ""
5710 IF MO$="S" THEN DISP "    POWER"
5720 IF MO$="SH" THEN DISP "POWER RELATED TO REFERENCE"
5730 IF MO$="D" THEN DISP "POWER RATIO(dB)"
5740 MI=99999
5750 MA=-99999
5760 DIM HEADER$[70]
5770 HEADER$=""
5780 FLA=0
5790 FOR COUNTER=1 TO SAMP ! BEGIN LOOP
5800 REM "READ DATA FROM 22XLA VIA 488XLI"
```

```
5810 REM "NON-TRIGGER ADDRESS = 02"
5820 ENTER 702 ; AT
5830 IF ABS (AT)=99999 THEN PRINT "OVERRANGE" @ GOTO 6070
5840 IF MO$ <> "S" THEN 5860
5850 IF REFER$="MILI" THEN AT=AT+30
5860 AT=AT/100
5870 IF RESOL=.01 THEN AT=AT/10
5880 REM "SEND DATA TO CRT OR PRINTER"
5890 PA(COUNTER)=AT
5900 MA=MAX (MA,AT)
5910 MI=MIN (MI,AT)
5920 IF MO$ <> "S" THEN 6030
5930 IF REFER$="MILI" THEN 5980
5940 IF RESOL=.1 THEN DISP USING 5950 ; PA(COUNTER)
     @ GOTO 6070
5950 IMAGE DDDD.D," dB "
5960 DISP USING 5970 ; PA(COUNTER) @ GOTO 6070
5970 IMAGE DDD.DD," dB "
5980 IF RESOL=.1 THEN DISP USING 5990 ; PA(COUNTER)
     @ GOTO 6070
5990 IMAGE DDDD.D," dBm" !FORMAT OUTPUT
6000 DISP USING 6010 ; PA(COUNTER" @ GOTO 6070
6010 IMAGE DDD.DD," dBm"
6020 IF REFER$="MILI" THEN 6030
6030 IF RESOL=.1 THEN DISP USING 6040 ; PA(COUNTER)
     @ GOTO 6070
6040 IMAGE DDDD.D," dB"
6050 DISP USING 6060 ; PA(COUNTER) @ GOTO 6070
6060 IMAGE DDD.DD," dB"
6070 WAIT INTER
6080 PRINT# 1 ; PA(COUNTER) ! PRINT ARRAY TO DATA FILE
6090 NEX COUNTER ! END LOOP
6100 ASSIGN# 1 TO * CLOSE DATA FILE
6110 DISP " "
6120 DISP "DO YOU WANT A PLOT ON CRT? (Y/N)"
6130 INPUT PAN$
6140 IF PAN$="N" THEN 6830
6150 IF PAN$ <> "Y" THEN 6120
6160 PLOTTER IS 1
6170 GCLEAR
6180 GRAPHALL
6190 ASSIGN# 1 TO  "22XLA:D700" ! OPEN DATA FILE
6200 LOCATE 30,180,15,95 @ GOTO 6220 ! RELOCATE PLOTTING AREA
6210 LOCATE 15,115,15,95
6220 IF MO$ <> "S" THEN 6240
6230 IF REFER$="MICRO" THEN SCALE 0,SAMP*TIM,-60,40
     @ GOTO 6250
6240 SCALE 0,SAMP*TIM,-100,100 ! SPECIFY USER UNITS
6250 IF SAMP*TIM/10<= .1 THEN FXD 2,0 ELSE FXD 1,0
6260 IF SAMP*TIM>99 THEN FXD 0,0
6270 LGRID -(SAMP*TIM/10),10,0,0,1,2 ! DRAW A GRID
```

```
6280 IF MO$ <> "S" THEN 6300
6290 IF REFER$="MICRO" THEN  MOVE  SAMP*TIM-SAMP*TIM/20,-74
     @  GOTO 6310
6300 MOVE SAMP*TIM-SAMP*TIM/20,-115 ! MOVE PEN
6310 LABEL "t(sec)"
6320 MOVE -(SAMP*TIM/10),-30
6330 DEG @ LDIR 90 ! LABEL DIRECTION TO 90 DEGREES
6340 IF MO$ <> "S" THEN LABEL "REL Power(dB)" @ GOTO 6400
6350 MOVE -(SAMP*TIM/10),-20
6360 IF REFER$="MILI" THEN LABEL "Power (dBm)" @ GOTO 6400
6370 IF FLA=0 THEN 6390 ELSE LABEL "Power (dBu)"
6380 GOTO 6400
6390 LABEL "Power (dB )"
6400 MOVE 0,0
6410 FOR INTE=1 TO SAMP
6420 READ# 1,INTE ; PA(INTE) ! READ DATA FROM DATA FILE
6430 PEN 2
6440 DRAW INTE*TIM,PA(INTE)
6450 NEX INTE
6460 LDIR 0
6470 PEN 1
6480 MOVE SAMP*TIM+SAMP*TIM/40,100 @ LABEL "max=";MA
6490 MOVE SAMP*TIM+SAMP*TIM/40,80 @ LABEL "min=";MI
6500 IF MO$ <> "S" THEN 6570
6510 IF REFER$ <> "MICRO" THEN 6570
6520 MOVE SAMP*TIM+SAMP*TIM/40,40 @ LABEL "max=";MA
6530 MOVE SAMP*TIM+SAMP*TIM/40,20 @ LABEL "min=;MI
6540 IF FLA=0 THEN 6560
6550 MOVE 0,-75 @ LABEL HEADER$ @ GOTO 6780
6560 IF PAN$="Y" THEN MOVE SAMP*TIM/2-SAMP*TIM/4,-75 @ LABEL
     "PRESS 'CONT' TO CONTINUE"
6570 IF FLA=0 THEN 6590
6580 MOVE 0,-120 @ LABEL HEADER$ @ GOTO 6780
6590 IF PAN$="Y" THEN MOVE SAMP*TIM/2-SAMP*TIM/4,-120 @ LABEL
     "PRESS 'CONT' TO CONTINUE"
6600 PAUSE
6610 ALPHA
6620 DISP @ DISP @ DISP @ DISP
6630 DISP "            DO YOU WANT A PLOT ON PLOTTER? (Y/N)"
6640 INPUT PL$
6650 IF PL$="N" THEN 6780
6660 IF PL$ <> "Y" THEN 6630
6670 CLEAR @ DISP "ENTER A HEADER (50 CHAR max)"
6680 INPUT HEADER$
6690 HA=LEN (HEADER$)
6700 IF HA>70 THEN 6670
6710 CLEAR
6720 DISP "LOAD PLOTTER WITH PAPER"
6730 DISP ""
6740 DISP "PRESS 'CONT' WHEN READY"
6750 PAUSE
```

```
6760 PLOTTER IS 705 @ CLEAR @ FLA=1
6770 DISP "PLOTTING" @ GOTO 6210
6780 CLEAR
6790 DISP "PLEASE WAIT"
6800 WAIT 1500
6810 GSTORE "GRAF"
6820 ASSIGN$ 1 TO  * ! CLOSE DATA FILE
6830 CLEAR
6840 PRINTER IS 1 @ GOTO 970
6850 CLEAR @ DISP USING 6860
6860 IMAGE """7/"""
6870 DISP "                              TEST COMPLETE"
6880 STOP
6890 CLEAR @ OFF KEY#
6900 OUTPUT 706 ;"RESET"
6910 DISP USING 6920
6920 IMAGE """4/"""
6930 DISP "            TEST SET 2275XQ IS ON REMOTE CONTROL"
6940 DISP @ DISP "              PRESS THE KEY OF YOUR OPTION"
6950 ON KEY# 1,"  SET UP" GOTO 7010
6960 ON KEY# 2," ACQUIRE" GOTO 8350
6970 ON KEY# 3,"  PRINT" GOTO 8640
6980 ON KEY# 4," RETURN" GOTO 970
6990 KEY LABEL
7000 GOTO 7000
7010 CLEAR @ OFF KEY#
7020 DISP USING 7030
7030 IMAGE """5/"""
7040 DISP "          TURN THE 'WE' DIP SWITCH ON THE REAR
     PANEL OF THE 2275XQ TO 'ON'"
7050 DISP @ DISP "              PRESS THE KEY OF YOUR OPTION"
7060 ON KEY# 1,"   MODE" GOTO 7130
7070 ON KEY# 2,"   UNITS" GOTO 7300
7080 ON KEY# 3,"WAV.LENGTH" GOTO 7480
7090 ON KEY# 4," FUNCTION" GOTO 7570
7100 ON KEY# 5,"  RETURN" GOTO 6890
7110 KEY LABEL
7120 GOTO 7120
7130 CLEAR @ OFF KEY#
7140 DISP USING 7150
7150 IMAGE """5/"""
7160 DISP               THIS WILL SET THE MODE OF OPERATION"
7170 DISP @ DISP "              PRESS THE KEY OF YOUR OPTION"
7180 ON KEY# 1,"    DC" GOTO 7240
7190 ON KEY# 2,"  ACEXT" GOTO 7260
7200 ON KEY# 3,"  ACINT" GOTO 7280
7210 ON KEY# 4,"  RETURN" GOTO 7010
7220 KEY LABEL
7230 GOTO 7230
7240 OUTPUT 706 ;"DC"
7250 GOTO 7010
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```
7260 OUTPUT 706 ;"ACEXT"
7270 GOTO 7010
7280 OUTPUT 706 ;"ACINT"
7290 GOTO 7010
7300 CLEAR @ OFF KEY#
7310 DISP USING 7320
7320 IMAGE ""5/""
7330 DISP "               THIS WILL SET THE MEASUREMENT UNITS"
7340 DISP @ DISP "              PRESS THE KEY OF YOUR OPTION"
7350 LET UNIT$=dBm"
7360 ON KEY# 1,"   DBM" GOTO 7420
7370 ON KEY# 2,"  WATT" GOTO 7440
7380 ON KEY# 3,"   REL" GOTO 7460
7390 ON KEY# 4," RETURN" GOTO 7010
7400 KEY LABEL
7410 GOTO 7410
7420 OUTPUT 706 ;"DBM" @ LET UNIT$="dBm"
7430 GOTO 7010
7440 OUTPUT 706 ;"WATT" @ LET UNIT$="Watt"
7450 GOTO 7010
7460 OUTPUT 706 ;"REL" @ LET UNIT$="dB"
7470 GOTO 7010
7480 CLEAR @ OFF KEY#
7490 DISP USING 7500
7500 IMAGE ""5/""
7510 DISP "             ENTER WAVELENGTH IN NANOMETERS" @ DISP
7520 DISP "                        RANGE IS 800 - 1800"
7530 INPUT TSWL
7540 IF TSWL<800 OR TSWL>1800 THEN 7480
7550 OUTPUT 706 ;"CAL";TSWL
7560 GOTO 7010
7570 CLEAR @ OFF KEY#
7580 DISP USING 7590
7590 IMAGE ""5/""
7600 DISP "              THIS WILL SET SOME CONTROL FUNCTIONS"
7610 DISP @ DISP "              PRESS THE KEY OF YOUR OPTION"
7620 ON KEY# 1,"   AUTO" GOTO 7700
7630 ON KEY# 2,"   HOLD" GOTO 7720
7640 ON KEY# 3,"   XMTR" GOTO 7740
7650 ON KEY# 4,"   LCD" GOTO 8190
7660 ON KEY# 5,"  RESET" GOTO 8330
7670 ON KEY# 6,"  RETURN" GOTO 7010
7680 KEY LABEL
7690 GOTO 7690
7700 OUTPUT 706 ;"AUTO"
7710 GOTO 7010
7720 OUTPUT 706 ;"HOLD"
7730 GOTO 7010
7740 CLEAR @ OFF KEY#
7750 DISP USING 7760
7760 IMAGE ""2/""
```

```
7770 DISP "     THESE ARE THE SOURCE MODULE CONTROL FUNCTIONS"
7780 DISP
7790 DISP "  OFF  =SETS THE MODULE TO THE 'OFF' STATE " @ DISP
7800 DISP "  FRQ  =SETS THE 'ON' STATE AND THE FREQUENCY OF
     THE MODULE
7810 DISP
7820 DISP "  CURRENT  = READS THE DRIVE CURRENT OF THE MODULE"
     DISP
7830 DISP "  W.LENGTH = READS THE WAVELENGTH OF THE MODULE"
7840 ON KEY# 1,"    OFF" GOTO 7910
7850 ON KEY# 2,"    FRQ" GOTO 7930
7860 ON KEY# 3," CURRENT" GOTO 8000
7870 ON KEY# 4," W.LENGTH" GOTO 8100
7880 ON KEY# 5," RETURN" GOTO 7570
7890 KEY LABEL
7900 GOTO 7900
7910 OUTPUT 706 ;"XMTR 0,0"
7920 GOTO 7740
7930 CLEAR @ DISP @ DISP @ DISP
7940 DISP "                ENTER MODULATION FREQUENCY" @ DISP
7950 DISP "                          RANGE IS: 0 OR 200-2000"
7960 INPUT TSFR
7970 IF TSFR=0 THEN 7990
7980 IF TSFR<200 OR TSFR>2000 THEN 7940
7990 OUTPUT 706 ;"XMTR";1;TSFR @ GOTO 7740
8000 CLEAR @ DISP "                                  PLEASE WAIT"
8010 OUTPUT 706 ;"XMTR_MA"
8020 ENTER 706 ; TSA$
8030 CLEAR
8040 DISP @ DISP @ DISP
8050 DISP "                           DRIVE CURRENT IS";TSA$
8060 DISP @ DISP @ DISP
8070 DISP "                        PRESS 'CONT' TO CONTINUE"
8080 PAUSE
8090 GOTO 7740
8100 CLEAR @ DISP "                                  PLEASE WAIT"
8110 OUTPUT 706 ;"XMTR_NM"
8120 ENTER 706 ; TSB$
8130 CLEAR @ DISP @ DISP @ DISP
8140 DISP "                       SOURCE WAVELENGTH IS";TSB$
8150 DISP @ DISP @ DISP
8160 DISP "                        PRESS 'CONT' TO CONTINUE"
8170 PAUSE
8180 GOTO 7740
8190 CLEAR @ OFF KEY#
8200 DISP USING 8210
8210 IMAGE """5/"""
8220 DISP "       THIS WILL TURN THE BACKLIGHT 'ON' OR 'OFF'"
8230 DISP @ DISP "              PRESS THE KEY OF YOUR CHOICE"
8240 ON KEY# 1,"    ON" GOTO 8290
8250 ON KEY# 2,"    OFF" GOTO 8310
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8260 ON KEY# 3,"  RETURN" GOTO 7570
8270 KEY LABEL
8280 GOTO 8280
8290 OUTPUT 706 ;"LCD 1"
8300 GOTO 7570
8310 OUTPUT 706 ;"LCD 0"
8320 GOTO 7570
8330 OUTPUT 706 ;"RESET"
8340 GOTO 7010
8350 CLEAR @ OFF KEY#
8360 DISP USING 8370
8370 IMAGE ""5/""
8380 DISP "      THIS WILL ACQUIRE DATA FROM TEST SET 2275XQ"
8390 DISP
8400 DISP "              ENTER NUMBER OF SAMPLES (max 1024)"
8410 INPUT TSS
8420 IF TSS<0 OR TSS>1024 THEN 8400
8430 ! CREATE "2275TS:D700",1024,8 ! YOU MAY USE TO CREATE
     DATA FILE
8440 ASSIGN# 1 TO "2275TS:D700"
8450 SHORT TSP(1024)
8460 CLEAR
8470 DISP USING 8480
8480 IMAGE ""5/""
8490 DISP "       ENTER SAMPLE INTERVAL IN SECONDS (min 0.2)"
8500 INPUT TST
8510 IF TST<.2 THEN 8490
8520 CLEAR @ DISP @ DISP @ DISP
8530 DISP "             DATA IS BEING ACQUIRED" @ DISP @ DISP
8540 DISP "                                   PLEASE WAIT"
8550 TST=TST*1000
8560 FOR TSNUM=1 TO TSS
8570 ENTER 706 ; TSDAT
8580 TSP(TSNUM)+TSDAT
8590 WAIT TST
8600 PRINT# 1 ; TSP(TSNUM)
8610 NEXT TSNUM
8620 ASSIGN# 1 TO  *
8630 GOTO 6890
8640 CLEAR @ OFF KEY#
8650 DISP USING 8660
8660 IMAGE ""5/""
8670 DISP "      THIS WILL PRINT THE DATA ACQUIRED BY THE
     2275XQ TEST SET"
8680 DISP @ DISP
8690 DISP "                     CHECK IF THE PRINTE IS READY"
8700 DISP @ DISP
8710 DISP "                     PRESS THE KEY OF YOUR OPTION"
8720 ON KEY# 1,"  GO ON" GOTO 8760
8730 ON KEY# 2,"  QUIT " GOTO 6890
8740 KEY LABEL
```

```
8750 GOTO 8750
8760 CLEAR @ OFF KEY#
8770 PRINTER IS 701
8780 DISP USING 8790
8790 IMAGE ""5/""
8800 DISP "                              PRINTING"
8810 ASSIGN# 1 TO  "2275TS:D700"
8820 PRINT "FIBER-OPTIC DATA ACQUIRED BY THE 2275XQ TEST SET"
8830 PRINT @ PRINT
8840 PRINT "PARAMETER: POWER";"        ";"UNIT:";UNIT$
8850 PRINT @ PRINT
8860 PRINT "POINT";"            ";"    VALUE"
8870 FOR TSX=1 TO TSS
8880 READ# 1,TSX ; TSP(TSX)
8890 PRINT TSX,TSP(TSX)
8900 NEXT TSX
8910 CLEAR @ DISP @ DISP @ DISP
8920 DISP "                        DATA HAS BEEN PRINTED"
8930 WAIT 1500
8940 GOTO 6890
8950 END
```

APPENDIX C

LABORATORY EXPERIMENT

This appendix contains a sample laboratory exercise that would use the automatic measuring system.

FIBER OPTIC AUTOMATED MEASUREMENTS

Purpose:

In this lab experiment you will become familiar with the use of an automated system for fiber optic testing.

Reference Reading:

Introduction to the HP-87 - Hewlett-Packard

OF235 OTDR Operator Manual - Tektronix

Equipment:

DEVICE	MODEL
COMPUTER:	HEWLETT PACKARD HP-87
REFLECTOMETER:	TEKTRONIX OF235 OTDR
MASS STORAGE:	HP82901M/S
PLOTTER:	HP 7470A
PRINTER:	HP 82905B
OPTIC FIBER	

General:

In this experiment an automated measurement setup comprised of the HP-87 computer, the OF235 Optical Time Domain Reflectometer and peripheral devices will be used to measure loss and to detect and locate faults in a single-mode fiber.

Optical Time Domain Reflectometer Background

An Optical Time Domain Reflectometer (OTDR) is basically a one-dimensional, close-circuit optical radar. It operates by launching brief pulses of laser light into a test fiber, then monitoring the amplitude and arrival time of light scattered back toward the launch end of the fiber.

This scattered light is the product of two distinct mechanisms. One is the Fresnel reflection that occurs as the light passes between two media with differing indices of refraction (for example, from a fiber into air); this is the case at fiber ends, breaks and connectors. The other one is the Rayleigh scattering due to inhomogeneities in the fiber along its length.

The OTDR can be used to measure the distance to breaks, faults and connectors in optic fibers. The time of travel for a light pulse from the launch end to the position of a Fresnel reflection is determined by the instrument, and knowing the index of refraction of the fiber under test, the distance from the launch end to the break can be calculated by.

$$\boxed{d = \frac{t.c}{2.n}}$$

where:

d = distance,

t = time between the two pulses,

c = speed of light in vacuum, and

n = refractive index of the fiber.

The OTDR also measures the total attenuation of the fiber link being tested. After a Fresnel reflection is detected the internal circuitry samples the Rayleigh backscattered signal immediately after the first reflection and preceding the next reflection. The two samples are subtracted and the result is a direct measure for the attenuation. As the distance between the reflections is known the internal microcomputer also calculates the characteristic attenuation of the fiber in dB/km.

Experiment Procedure:

The HP-87 has been programmed to set up the OF235 OTDR, to make data acquisition and to make hard copy of the results.

Briefly, The experiment will be conducted as follows:

1) You will be provided with the equipment setup as in Figure 1. Switch on all equipment (with the HP-87 being the last one). In this way the computer will load and run the system program on its own. If it happens that the HP-87 is not the last device to have the power on, you should reset the system pressing the "RESET" key on the HP-87 keyboard, load the program with the following command:

LOAD "Autost"

and run it pressing the "RUN" switch. As long as the program is running, the power light will blink on and off. The program will automatically go to the main menu.

You can stop the program from running any time pressing the "RESET" key.

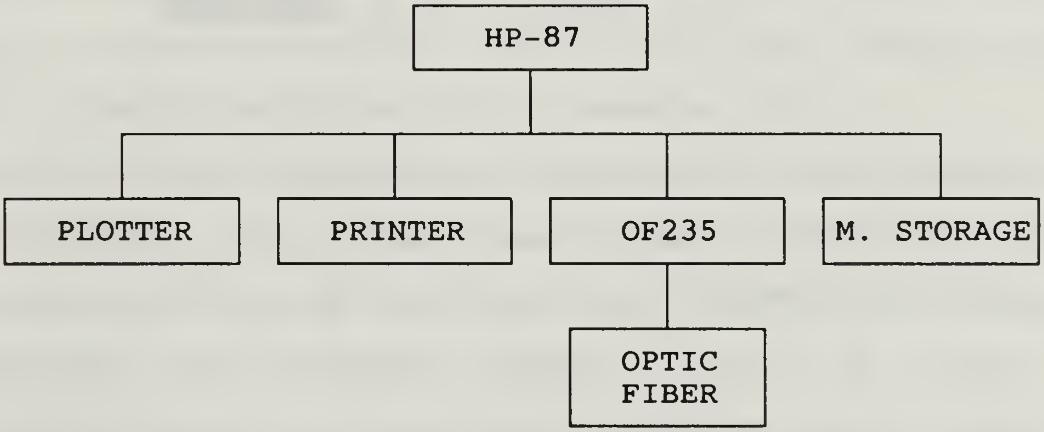

Figure 1. The Experiment setup.

2) Press the key "K1" on the keyboard to execute the STARTUP routine. Check if the devices involved in the experiment are

responding to the controller commands. If not, call for the lab technician's assistance. Return to the main menu.

3) Go to the devices menu, chose the OF235 option and start the SETUP routine. You will be prompted to the set-up options. At this point you are supposed to observe on the OF235 display a waveform like the one in Figure 2.

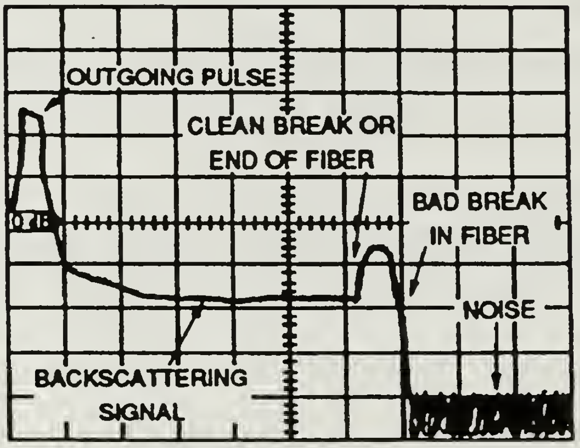

Figure 2. Typical Fiber Display.

You may play with the set-up options and observe the effect on the display. Explain the changes in the waveform. At this point the "REMOTE" light should be "ON" and all panel controls except the "LOCAL", "POWER", "INTENSITY" and "POSITION" are inoperative. The panel gains control if the "LOCAL" key is pushed.

4) Set the OF235 with the following values:

FILTER	MIN
PULSE	MEDIUM
READ MODE	DIST
VERTICAL SCALE	5
INDEX REFR	1.499
DIST/DIV	2000

5) Exit the "SETUP" and go to the "ACQUIRE" routine. You will see some data acquisition alternatives. Press the "SWEEP" and then the "CONTIN" options. The last move will cause repeated laser sweep along the fiber to occur and the measured data will be stored in the OF235 memory. Use the "STOP" option to stop the continuous sweep. This will make the data available to be read by the controller. At this point you may see the number of averaged waveforms used in the sweep pressing the "AVGS" corresponding key. Do that and then Return.

6) Press the key corresponding to the "DIST" option and enter "0" as the point you want data acquisition to begin. Once done press the "DONE" option key. This will take you back to the "OF235" option of the devices menu.

7) Now you are ready to output the measurement results. Press the key corresponding to the "PRINT" option to be able to print the measured points along the fiber. With this data you can evaluate the attenuation along the fiber.

8) Press the key corresponding to the "PLOT" option to be able to obtain a plot of the reflected power along the fiber. You can also obtain a record of the displayed waveform using the "RECORD" option. Press the corresponding key and the waveform will be sent to the strip chart recorder of the OF235.

Suggested Exercise

Suppose you are in a practical field environment and the specifications of an optic fiber got lost (the label on the fiber spool may have peeled off). Without the specific index of refraction value, an accurate length measurement is no longer possible. Using an OTDR, find a method to reestablish the correct index of refraction.

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